Animal 18 (2024) 101104

Contents lists available at ScienceDirect

Animal

The international journal of animal biosciences

The effects of feeding sows at onset of farrowing supplemental energy (blend of carbohydrates and glycerol) on farrowing kinetics and piglet vitality

R.F. Carnevale [a], B.B.D. Muro [a], D.F. Leal [b], L.K.S. Alves [a], M.S. Monteiro [c], N.A.C. Gomes [a], F.A. Pereira [d], F.N.A. Ferreira [d], C.S.S. Neta [d], T.T.N. Watanabe [e], G.W. Almond [e], C.A.P. Garbossa [a,*]

[a] Department of Nutrition and Animal Production, School of Veterinary Medicine and Animal Sciences, University of São Paulo (USP), Campus Pirassununga, SP, Brazil
[b] University of São Paulo, Brazil
[c] Nerthus Pesquisa e Desenvolvimento LTDA, São Carlos, SP 13563-651, Brazil
[d] Technical Services Department, Agroceres Multimix, Rio Claro, SP 13502-741, Brazil
[e] Department of Population Health & Pathobiology, College of Veterinary Medicine, North Carolina State University (NCSU), Raleigh, NC, USA

ARTICLE INFO

Article history:
Received 16 July 2023
Revised 30 January 2024
Accepted 1 February 2024
Available online 8 February 2024

Keywords:
Apgar
Blood glucose
Colostrum intake
Glycemia
Pigs

ABSTRACT

Delivering piglets is one of the most energy-demanding activities sows undergo in their lifetime. Sows can have myometrial contractions from 2 to 12 h before the first piglet is expelled as well as a nest-building behavior. Thus, when the first piglet is delivered, the female has already used part of her energy supply. When the sow gets exhausted due to lack of energy, the farrowing process can be interrupted, causing damage to the viability and vitality of the piglets. In the present study, we evaluated the effects of feeding sows an energy supplement at the onset of farrowing on farrowing kinetics and piglet vitality. The energy supplement consisted of a blend of carbohydrates and glycerol which provides 439 kJ of metabolizable energy per kg of metabolic weight. A total of 180 sows were used. At the onset of farrowing, sows were assigned to one of the following treatments: sows that were not supplied energy at the onset of farrowing, serving as controls (**CON**, n = 85); sows fed the energy supplement at the onset of farrowing (**ESP**, n = 95). Farrowing kinetics, blood glucose concentration, and piglet vitality were recorded for each sow. Blood glucose concentration was assessed by puncturing the auricular vein and using a portable glucometer at four different time points: after the birth of the 1st piglet (T0), and at 20 (T20), 40 (T40), 80 (T80), and 180 (T180) min after the birth of the 1st piglet. The vitality of the 1st, 6th, 12th, 17th, and 20th piglet born was evaluated using the Apgar score. Piglet birth weight and average colostrum intake were measured. The farrowing duration was 20 min shorter ($P < 0.05$) for ESP sows in comparison with CON sows. Sows from ESP treatment had higher ($P \leq 0.05$) blood glucose concentration at T20 and T40 compared to the CON sows. The inter-piglet birth interval was shortened ($P < 0.05$) by 14 min between the 1st and 2nd piglet for the ESP treatment. The 17th and 20th piglets born from ESP sows had higher ($P < 0.05$) Apgar score compared to piglets of the same birth order from CON sows. Colostrum intake was higher ($P < 0.01$) for piglets born from ESP sows. Litter growth performance did not differ ($P > 0.05$). In conclusion, feeding a blend of carbohydrates and glycerol as an energy supplement for farrowing sows improved farrowing kinetics and piglet vitality score.

Implications

The sow can get exhausted due to lack of energy, even before the expulsive stage of the farrow start. This can result in decreased uterine contractions or even interruptions in the farrowing process, which can in turn jeopardize farrowing outcomes. Sows were fed an innovative energy supplement which was efficient in decreasing farrowing duration and improve piglets' colostrum intake and overall vitality. Supplying sows' extra at the onset of farrowing is a feasible solution to accelerate piglet delivery that can better endure the challenges of birth and adapt to extra-uterine life.

Introduction

Despite numerous and continuous advances in genetics, management and health, piglet mortality is still pervasive in

* Corresponding author.
E-mail address: cgarbossa@usp.br (C.A.P. Garbossa).

https://doi.org/10.1016/j.animal.2024.101104
1751-7311/

pig production (Farmer and Edwards, 2022). According to available data, more than 25% of total born piglets do not survive to weaning (Baxter and Edwards, 2018; Cornelison et al., 2018; Gourley et al., 2020), with mortality peaking within the first 72 hours after birth (Gourley et al., 2020; Muns and Tummaruk, 2016).

Farrowing is a crucial event for piglet survival, it is during this time that piglets have the highest odds of dying (van den Bosch et al., 2023). The majority of deaths that occur during farrowing are a result of perinatal asphyxiation (Alonso-Spilsbury et al., 2005). It is estimated that 15–20% of born-alive piglets are hypoxic at birth (Langendijk and Plush, 2019). Hypoxic piglets have lower vitality, reduced thermoregulatory capacity, and take longer to reach the udder and suckle, which increases the risk of death in the first week after birth (Alonso-Spilsbury et al., 2005; Herpin et al., 1996). Evidence from studies demonstrates that in the last 18 years, the duration of farrowing has increased along with the increase in litter size (van den Bosch et al., 2023, van Dijk et al., 2005). It increases the numbers of stillborn piglets (Oliviero et al., 2010), mainly as a result of perinatal asphyxia.

The process of farrowing is highly energy-demanding (Vallet et al., 2013). Likewise, colostrum production and glucose uptake by several tissues, in response to insulin secretion, may reduce glucose availability to support uterine contractions (Feyera et al., 2018). This can make sows more susceptible to fatigue during farrowing, impairing the number and intensity of uterine contractions, which in turn increases the duration of farrowing and consequently stillborn prevalence (van Kempen, 2008).

Most of the energy in the diet is absorbed in the form of glucose in the gastrointestinal tract of sows during the first 4–6 hours after feed intake (Serena et al., 2009; Theil et al., 2011). The mammary gland consumes plasma glucose very rapidly in the prepartum period, regardless of insulin levels, due to a high metabolic activity to produce colostrum (Feyera et al., 2018). Several other tissues also uptake glucose rapidly due to insulin secretion, thus part of the absorbed glucose is not available for the uterus (Feyera et al., 2018) Therefore, the blood glucose concentration is a limiting factor for an adequate farrowing process.

Reported studies have demonstrated that sows with adequate blood glucose concentration at the onset of farrowing have improved farrowing processes (Carnevale et al., 2023; Feyera et al., 2018; Oliveira et al., 2020; Yang et al., 2019). The blood glucose concentration at farrowing may be modulated by feed intake, fasting period and feed composition (Feyera et al., 2018; Gourley et al., 2020). Feyera et al. (2021) and Bruun et al. (2023) concluded that it is important to deliver at least between 3.0 and 3.7 kg/d before farrowing to improve farrowing outcomes and litter growth in the subsequent lactation. In the study of Feyera et al. (2018), the broken-line model indicated that sows would have benefited from receiving a meal shortly before farrowing, which would decrease the fasting period and increase blood glucose concentration. However, this faces a practical constraint as it is indicated that sows might benefit from receiving up to as much as 8 daily meals on the day of farrowing (Feyera et al., 2018). Therefore, the development of convenient nutritional strategies to readily supply sows energy at the onset of farrowing would improve energy status during farrowing. We hypothesize that feeding sows supplemental energy at the onset of farrowing can decrease farrowing duration, thus reducing the stillbirth rate and improving piglet vitality. Based on the foregoing, the aim of the present study was to evaluate the effects of supplying energy in the form of a blend of carbohydrates and glycerol on farrowing kinetics, stillbirth rate, and piglet vitality at birth.

Material and methods

This study was approved by the Committee on Ethics in Animal Use (**CEUA**) of the Agroceres Multimix under protocol n° 38.21 and co-validated by the CEUA of the School of Veterinary Medicine and Animal Science (FMVZ-USP), University of São Paulo, under protocol no. 1541030220.

Animals, management, housing and feeding

The study was performed between September and October 2021 at a commercial farm with an inventory of 3 500 sows, located in Patos de Minas, Minas Gerais, Brazil. A total of 180 cross-bred sows (Landrace × Large White, PIC Cambrough 25®, Patos de Minas, MG, Brazil), from two consecutive batches, with parity ranging from 1 to 8 were selected. Approximately 1 week before expected farrowing, sows were moved to the farrowing unit, housed individually in crates with partly slatted floor, equipped with a heating mat to establish a warm microclimate for the piglets. After movement to the farrowing house, sows were fed a standard lactation diet (Table 1). Sows had *ad libitum* water via a drinking nipple. Daily feeding time and sows' feed intake during lactation were controlled with the use of electronic feeders (Gestal Solo, JYGA Technologies, Quebec, Canada). The sows were supervised in 24-h shifts around farrowing. Within 24 h after farrowing, litter size was standardized to 14–16 piglets per sow, by cross-fostering piglets to sows in the same experimental group.

Table 1
Dietary ingredients and calculated composition of sow lactation feed.

Item	Lactation diet
Ingredient g/kg, as-fed basis	
Corn	601.4
Soybean meal, 46 CP	260
Soybean Oil	22.6
Sugar	50
Lactation supplement[1]	60
AGFIX ZEA 3[2]	3
AGACID[3]	3
Calculated composition	
Metabolizable energy MJ/kg	16.3
DM (%)	89.26
CP (%)	17.53
SID Lysine (%)	1.13
Fat (%)	4.91
Crude fiber (%)	2.46
Ash (%)	5.38
Calcium (%)	0.75
Phosphorus (%)	0.52

SID: standardized ileal digestibility.
[1] Provided per kg of supplement: Lysine (min) 56.5 g, Methionine (min) 25 g, Threonine (min) 47 g, Tryptophan (min) 5 900 mg, Valine (min) 33.8 g, Ca (min) 80.33 g (max) 81.33 g, Cu (min) 1732.5 mg, Cr (min) 3.33 mg, Fe (min) 2 000 mg, F (max) 400 mg, P (min) 38 g, I (min) 30 mg, Mn (min) 1 200 mg, Se (min) 11.9 mg, Na (min) 26.7 g, Zn (min) 2 400 mg, folic acid (min) 29.9 mg, pantothenic acid (min) 400 mg, Biotin (min) 8.35 mg, Choline (min) 10 g, Niacin (min) 699.9 mg, vitamin A (min) 200 000 UI, Thiamine (mín) 43.9 mg, vitamin B12 (min) 500 mcg, Riboflavin (min) 80 mg, Pyridoxine (min) 43.90 mg, vitamin D3 (min) 67 500 UI, vitamin E (min) 1 000 UI, vitamin K (min) 66 mg, Beta Mananase 13 330 U, Phytase 8333.3 FTU, *Lactobacillus acidophilus* 137.5 10^6 CFU, *Lactobacillus bulgaricus* 137.5 10^6 CFU, *Lactobacillus plantarum* 84 10^6 CFU, *Lactobacillus rhamnosus* 137.5 10^6 CFU.
[2] Provided per kg: bentonite 690 g, silymarin 500 mg.
[3] Provided per kg: citric acid 210 g, calcium formate 450 g, sodium benzoate 400 g.

Experimental design

This study was conducted using a randomized block design. Batch and parity were used as blocks and sows were allocated to one of two groups, **ESP** (n = 95): sows fed at onset of farrowing (birth of first piglet) the energy supplement, providing 439 kJ of metabolizable energy per kg of metabolic weight of the sow (the supplement was fed only once for the sows), and **CON** (n = 85): non-supplemented sows. All the sows were weighed at transference to the farrowing room. The trial was conducted in two batches.

The energy supplement consisted of a blend of carbohydrates, resistant starch and glycerol. The carbohydrates and glycerol were chosen based on their ability to be easily absorbed to ensure a prompt increase in glycemia and be substrates to uterine contractions through oxidation, while the resistant starch was included to provide an energy source later in the farrowing process through short-chain fatty acids that result from its fermentation by the hindut microbiota. The supplement of the above-mentioned ingredients in the following proportions: 25% malt extract (Liotécnica Tecnologia em Alimentos, S.A., São Paulo, Brazil), 25% high-amylose maize starch (i.e., a starch source with ~ 72% of amylose - Hylon VII - Ingredion Brasil Ingredientes Ltda), and 50% glycerol. The glycerol and malt extract used were in a liquid presentation; thus, the final blend of the ingredients was in a paste consistency. The energy supplement had a calculated metabolizable energy of 163 MJ/kg.

The amount of supplement fed to each sow was calculated based on the metabolic weight of the female that was estimated as the BW of the sow at the arrival in the farrowing room to the power of 0.75. After being weighed based on the metabolic weight of the sow, the supplement was stored in a plastic bag and identified. At birth of the first piglet, the supplement was fed directly into the mouth of the sow, and the animals voluntarily ate it. No significant spillage was observed. The average amount of the supplement that was fed to sows was 193 g, ranging from 153 to 262 g.

All sows were closely monitored during farrowing starting from the birth of the first piglet to the expulsion of the placenta. Farrowing kinetics, piglets' vitality, and blood glucose concentration were recorded for each sow.

Sample Collection, measurements and calculations of parameters

The backfat thickness and loin depth of each sow were evaluated when entering the farrowing crate, with an ultrasonic device (KX2000G - VET Chison; China, equipped with a 3.5 MHz linear transducer) at the P2 position (Maes et al., 2004). Sows were also weighed at entering the farrowing crate and at weaning. Data regarding sows' feeding intake during lactation were collected using a computerized feeding system (Gestal Solo, JYGA Technologies, Quebec, Canada) from day 1 postfarrowing up to day 21.

For each litter, the numbers of live-born (**LB**), stillborn (**SB**), mummified (**MM**), and total born, that was the sum of LB, SB and MM piglets were recorded along with sex, and time of birth. Piglets were classified as stillborn if they did not breathe and moved immediately after birth. Inter-piglet birth interval was calculated for each as the time since the previous piglet was born; therefore, the first-born piglets did not have this parameter according to this definition. When two piglets were born successively within less than a minute, the inter-piglet birth interval was the same for both piglets. Farrowing duration was defined as the time elapsed between the birth of the first-born and the last-born piglet in the litter. The time for total placental expulsion was recorded. The average birth interval was also calculated by dividing farrowing duration by the total born. The use of oxytocin and manual obstetric intervention were recorded for each sow and piglet.

The blood glucose concentrations were assessed using a portable glucometer (Accu-Chek Guide Meter^{TM}, Roche Diabetes Care, Inc) as described by Carnevale et al. (2023). The first measurement was performed after the birth of the first piglet and was considered as time T0. Subsequent measurements were performed after 20 min (**T20**), 40 min (**T40**), 80 min (**T80**) and, 180 min (**T180**). The venous blood samples were collected by puncture of the auricular vein with a 25 g × 8 mm gauge needle.

The Apgar score was applied to evaluate piglet vitality, as described by Martinez et al. (2020), five parameters were evaluated: respiratory latency, heart rate, snout skin color, latency to stand up and meconium staining. Each parameter received a score ranging from zero to two, and then summed to get the final score. Higher scores mean better vitality. This analysis was performed in the piglets of order 1, 6, 12, 17 and 20 from 99 litters and always by the same observer to avoid bias. The parameters and scores are described in Table 2.

Immediately after birth, piglets were weighed and received an individual ear tag. Twenty four hours on average (23–25 h) after birth of the first piglet, they were weighed again in order to estimate colostrum intake. Colostrum intake was estimated based on the mechanistic model as described by Theil et al. (2014). Potential colostrum intake of piglets dying within 24 h after birth was not calculated. Litters were weighed at 3, 7, 14 and 21 days of age.

Colostrum samples were collected from 12 sows of each treatment. Samples were collected 40 min after the onset of farrowing through manual milking from multiple teats. Colostrum samples obtained from each sow were immediately identified and stored at −20 C until chemical analyses. To analyze the composition of colostrum, different methods from the Association of Official Analytical Chemists (2005) and previously described by Araújo et al. (2020) were used. All analyses were carried out in triplicates Soxhlet extraction method (method 920.39) and Kjeldahl total nitrogen method (method 2001.11) were used to determine fat and nitrogen content, respectively. To determine ash content, samples were incinerated in a muffle furnace at 550 C for 6 h and the carbonizated leftovers were analyzed (method 942.05). To determine calcium, sodium, and phosphorus concentrations, atomic absorption spectrometry was utilized. Lactose content was estimated according to the Lane Eynon method (Lane and Eynon, 1923).

Statistical analyses

The assumption of normality and homogeneity of variance were graphically evaluated (histogram, normal *P* plot of residuals) and tested by Shapiro-Wilk and Barlett, respectively. Models that fulfilled the assumptions of normality and homogeneity of variance were subjected to ANOVA. Models that did not fulfill the assumptions of normality and homogeneity of variance were analyzed by generalized linear mixed models, fitted to the distribution of the dependent variable (function lmer, R-package lme4). The sow was considered as the experimental unit in all models. The data were presented as mean ± standard error of the mean (SEM), and

Table 2
Score to assess piglet vitality performed in the 1st, 6th, 12th, 17th, and 20th piglets.

Parameter	Score		
	0	1	2
Respiratory latency (s)	≥ 60	16 –60	≤ 15
Heart rate (beats/min)	0 ≤ 110	121–160	≥ 161
Snout skin color	Pale	Cyanotic	Pink
Latency to stand up (min)	≥ 5	1–5	≤ 1
Meconium staining (% of the body)	> 50%	< 50%	0

the results were considered significant at $P < 0.05$, with a trend towards significance at $0.05 \leq P \leq 0.10$. Statistical analyses were performed using software R (R Core Team, version 4.2.0).

Backfat thickness, loin depth, sows' BW, sows' feed intake during lactation (days 1–21 postfarrowing), farrowing duration, average birth interval, total piglets born, live-born piglets, colostrum composition, and colostrum intake were analyzed by ANOVA, with the following model: $Y_{ijkl} = \mu + \alpha_i + \beta_j + \rho_l + \varepsilon_{ijkl}$, where Y_{ijkl} is the measured dependent variable, μ is the mean, α_i is the fixed effect of the treatment (i = CON and ESP), β_j is the block effect of batch (n = 2), ρ_l is the block effect of parity (n = 8) and ε_{ijk} is the residual error. The number of total born piglets was used as a covariate to the model of farrowing duration as a dependent variable.

Glycemia during farrowing, apgar score and the inter-piglet birth interval were analyzed by repeated measure by mixed models using lme4 package in software R. For these models, the sow was included as a random effect, batch, parity, and time were included as a fixed effect.

Percentage of stillborn piglets, mummies as well as the binary variables (manual intervention and oxytocin injection) were analyzed by generalized linear mixed models using lme4 package in software R and were fit using binomial distribution.

Apgar score and the inter-piglet birth interval were analyzed by generalized linear mixed models with repeated measure, using lme4 package in software R and were fit using gamma distribution. The number of piglets to each birth order by treatment can be found in Supplementary Table S1.

Results

Loin depth at entrance in the farrowing unit differed ($P < 0.05$) between groups (Table 3). Sows from the ESP group had on average 2.2 mm more loin depth than CON sows. The backfat thickness, weight at entrance, and weight at weaning were similar in both groups ($P \geq 0.1$). Sows fed the energy supplement lost 11.21% of their initial weight while control sows lost 10.03% ($P > 0.1$). Sows' feed intake did not differ ($P > 0.05$) between groups throughout lactation, sows from ESP consumed on an average of 5.41 ± 0.19 k g/d and sows from CON group consumed on an average of 5.71 ± 0. 19 kg/d.

In the ESP group, 19% of the sows were injected with oxytocin, and 21% received manual obstetric intervention. No differences ($P > 0.10$) were found when comparing these parameters with the CON group, which had 13.7 and 29.5% for oxytocin injection and manual obstetric intervention, respectively.

The results of farrowing outcomes are presented in Table 4. No difference ($P > 0.1$) was found in total born, LB, SB, and MM between groups. Sows in the ESP group had, on average, farrowing 20 min shorter ($P < 0.05$) than sows in the CON group. The average birth interval was also shorter ($P < 0.5$) for ESP sows. When analyzing the farrowing duration of sows that did not receive manual obstetric intervention, ESP sows had a tendency ($P = 0.08$) for shorter farrowing duration than CON sows, with similar ($P > 0.05$) litter sizes ($P > 0.05$) for LB, SB or MM piglets between groups (Table 4).

When analyzing blood glucose within the same group, CON sows had similar values ($P > 0.10$) at all time points. ESP sows had similar ($P > 0.1$) blood glucose values at T20, T40 and T180. These three time points for supplemented animals had higher values than T0 ($P \leq 0.05$), whereas T80 was similar to all of the measurements ($P > 0.1$). Sows from the ESP group had higher blood glucose concentrations at T20 and T40 ($P \leq 0.05$) compared to the CON group. (Fig. 1). At T0, T80 and T180, no difference was found between groups ($P > 0.05$).

The inter-piglet birth interval was analyzed for each birth order (Fig. 2). This parameter was considered zero for the first piglet born. The second piglet born from ESP sows had a shorter inter-piglet birth interval compared to piglets of the same birth order in the CON group ($P < 0.05$) (24 ± 3 min vs 38 ± 5 min). This difference also tended to occur for the piglets of order 13, 14, and 15 (11 ± 1 min vs 16 ± 2 min, 10 ± 1 min vs 14 ± 2 min, and 11 ± 2 min vs 15 ± 2 min for ESP and CON groups, respectively) ($P < 0.1$).

The mean Apgar value for piglets born from sows in the ESP group was similar, regardless of birth order (Fig. 3). For piglets born from CON sows, there was a decrease in mean Apgar values with the course of the farrowing. In this group, the 12th piglets showed lower values when compared to the 1st piglets ($P < 0.05$). Piglets of order 17 showed reduced Apgar values when compared to piglets of order 1 and order 6 ($P < 0.05$). Additionally, piglets of order 20 had lower mean Apgar values than the 1st, 6th, and 12th piglets ($P < 0.05$). Comparing both groups, the CON group showed decreased values of Apgar ($P < 0.05$) for piglets of order 17 and order 20.

Piglets born from ESP sows ingested on average 307 ± 4 ml of colostrum, while piglets born from CON sows ingested 290 ± 4 ml of colostrum ($P < 0.01$). From all the components analyzed in the colostrum (Table 5), only the fat content was higher for CON sows ($P < 0.05$). Litter growth performance evaluated throughout lactation did not differ ($P > 0.05$) between groups (Table 6).

Discussion

The energy status of the parturient sow and the energy availability for myometrial contractions may influence farrowing kinetics and piglets' survivability (Liu et al., 2021). The uterus extracts mainly glucose and triglycerides from the blood to use as an energy source during farrowing (Feyera et al., 2018). Most likely, the glycerol resulting from the hydrolysis of the triglycerides is used by the myometrium as a glucogenic substrate. Therefore, the myometrium is mainly reliant on energy from glucose oxidation to support its intense contractions during farrowing. Several recent studies reported that farrowing traits may be affected by diet

Table 3
Sow characteristics of each experimental group.

Item	Treatment		SEM	*P-value*
	ESP	CON		
Backfat thickness (mm)	16.1	16.2	0.7	0.90
Loin depth (mm)	58.5	56.3	1.1	0.04
Weight at entrance in the farrowing unit (kg)	272.0	267.0	4.9	0.20
Weight at weaning (kg)	247.0	244.0	5.4	0.50
Weight loss (kg)	30.5	26.8	5.4	0.30
Parity	2.5	2.6	0.2	0.80

ESP (n = 95): sows fed an energetic supplement at the onset of farrowing, and CON (n = 85): non-supplemented females.
Statistical difference was set at $P < 0.05$.

Table 4
Sow farrowing outcomes between experimental groups.

Item	Treatment		SEM	*P-value*
	ESP	CON		
All sows				
Number of sows	95	85		
Farrowing duration (min)[1]	200	220	18.5	0.03
Average birth interval (min)[2]	12.1	13.8	1.12	0.02
Total born (piglets/litter)	17.3	17.4	0.41	0.90
Liveborn (piglets/litter)	15.8	15.3	0.54	0.30
Mummies (%)[3]	3.5	5.2	1.00	0.05
Stillborn (%)[3,4]	5.0	5.7	0.58	0.40
Colostrum intake (ml/piglet)	307.0	290.0	4.00	< 0.001
Sows with no manual obstetric intervention				
Number of sows	75	60		
Farrowing Duration (min)[1]	210	229	17.6	0.08
Average birth interval (min)[2]	13.3	14.9	1.03	0.06
Total born (piglets/litter)	17.4	17.6	0.53	0.8
Liveborn (piglets/litter)	15.4	16.1	0.52	0.2
Mummies (%)[3]	2.9	4.9	0.18	0.01
Stillborn (%)[3,4]	4.5	5.9	0.84	0.1
Colostrum intake (ml/piglet)	298.4	296.4	1.58	0.27

ESP (n = 95): sows fed an energetic supplement at the onset of farrowing, and CON (n = 85): non-supplemented females.
Statistical difference was set at $P < 0.05$.
[1] Time elapsed between the birth of the first and the last piglet.
[2] Average birth interval: farrowing duration divided by total born piglets.
[3] Analyzed by generalized linear mixed models fitted using binomial distribution.
[4] Number of stillborn piglets out of liveborn + stillborn piglets.

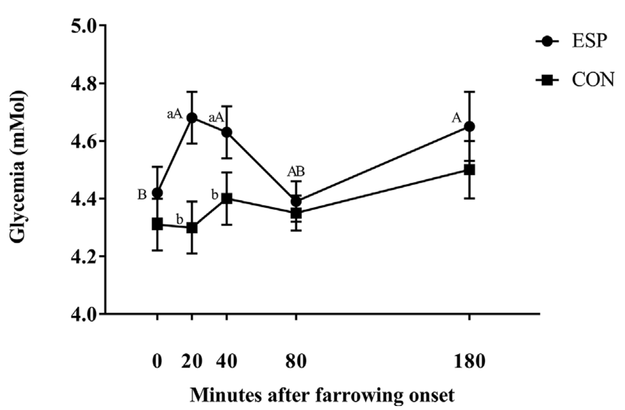

Fig. 1. Glycemic curves of ESP (n = 95, sows fed an energetic supplement at the onset of farrowing) and CON (n = 85, non-supplemented females) groups. Measurements were performed at the onset of farrowing (T0), 20 (T20), 40 (T40), 80 (T80) and 180 (T180) min after the first measurement. Data are presented as the mean ± SEM. Different upper-case letters indicate statistical differences ($P < 0.05$) within a group. Different lower-case letters indicate statistical differences ($P < 0.05$) between groups.

and / or feeding management (Feyera et al., 2018; Feyera and Theil, 2017; Gourley et al., 2020; Oliveira et al., 2020; Vallet et al., 2013). The energy supplement tested in the present study increased blood glucose shortly (< 40 min) after ingestion and decreased by 20 min the farrowing duration. In agreement, Oliveira et al. (2020) found a decrease of 40 min in farrowing duration of sows that received 500 g of an energetic supplement composed by 250 g of lactation diet and 250 g of sugar from sugar cane at the expected day of farrowing. It is hypothesized that the easily digestible ingredients (malt extract and glycerol) included in the supplement of the present study supplied glucogenic energy to support uterine contractions and accelerated the piglets' delivery.

Interestingly, the present study showed that the 2nd piglet born had the longest inter-piglet birth interval among all the piglets. The energetic supplement decreased, on average, 34% (13 min) of the time elapsed to the birth of the 2nd piglet. The time when the 2nd piglet was born, regardless of treatment, coincides with the time elapsed after the extra energy intake when the glycemia reached its peak, which support the hypothesis that the supplement provided greater glucogenic substrate for uterine contractions and it accelerated piglets' delivery. Also, the supplement decreased, on average, 31% (5 min), 29% (4 min), and 26% (4 min) of the time elapsed to the birth of the 13th, 14th, and 15th piglet. More studies are needed to understand the mechanism behind this finding, but a possible hypothesis is a greater availability of substrate for uterine contraction coming from the metabolism of the short-chain fatty acids resulting from the fermentation of resistant starch in the hindgut. Growing pigs fed a diet containing 70% purified resistant starch (80% amylose) had high flow (> 1 mMol/min) of total chain fatty acids in the portal vein over 12 h after feeding and with the peak of total short-chain fatty acids at between 40 and 150 min after feeding (Regmi et al., 2011).

The main objectives of decreasing farrowing duration are to minimize postfarrowing health problems in sows and improve piglets' survivability. Recent studies found a positive association between farrowing duration and stillbirth rate in hyperprolific sows (Björkman et al., 2017; Liu et al., 2021). However, in the present study, the stillbirth rate was similar between the two groups, even with a more prolonged farrowing observed in CON-sows. It is noteworthy that considering the litter size, the farrowing duration in this farm is overall short, which may have prevented from observing a significant treatment response on stillborn rate.

The mechanisms behind intrapartum stillbirth occurrence appear to be multifactorial. Sows-related factors such as parity, body condition score, genetics, uterotonic use, insufficient energy for uterine contractions, constipation, litter size have already been described to affect stillbirth rate (Björkman et al., 2017; Feyera et al., 2018; Leenhouwers et al., 1999; Muro et al., 2021; Oliveira et al., 2020). Several piglet- and environmental-related factors were also described to be associated to stillbirth rate (Edwards et al., 2019; Langendijk et al., 2007; Langendijk and Plush, 2019; van Dijk et al., 2008; Wegner et al., 2016). Thus, reducing farrowing duration might not be enough to reduce the stillbirth rate, especially in herds that do not experience prolonged farrowings.

Asphyxia-associated symptoms, such as reduced vitality, and a higher risk of stillbirth' are a direct effect of the interruptions in

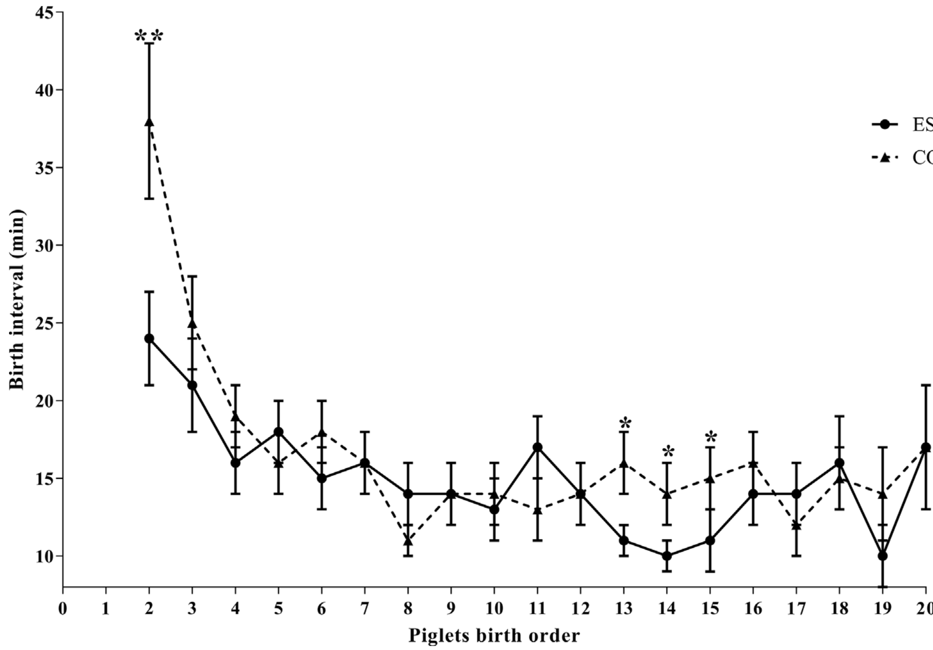

Fig. 2. Birth intervals of piglets born from sows in ESP (n = 95, sows fed an energetic supplement at the onset of farrowing) and CON (n = 85, non-supplemented females) groups. Data are presented as the mean ± SEM. * P < 0.05–0.10. ** P < 0.01–0.05.

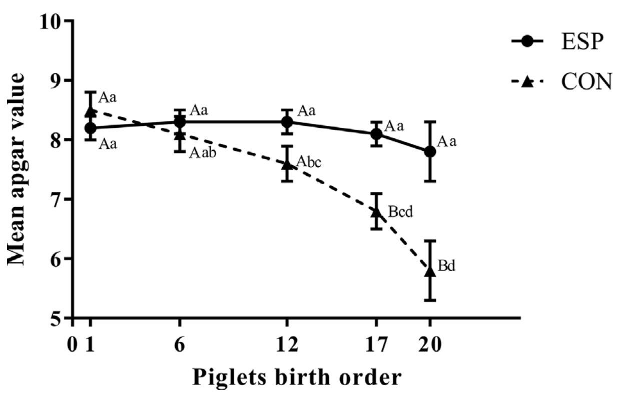

Fig 3. Mean Apgar values calculated for the 1st, 6th, 12th, 17th, and 20th piglets from sows in ESP (n = 95, sows fed an energetic supplement at the onset of farrowing) and CON (n = 85, non-supplemented females) groups. Data are presented as the mean ± SEM. Different lower-case letters indicate statistical differences (P < 0.05) within a group. Different upper-case letters indicate statistical differences (P < 0.05) between groups.

oxygen supply resulting from the repeated uterine contractions that the fetuses experience during the farrowing process (Herpin et al., 1996; van Dijk et al., 2008). Therefore, piglets later in the birth order are more prone to show reduced vitality as they are more exposed to oxygen deprivation (Langendijk et al., 2018). Apgar score results from piglets born from CON-sows corroborate with this notion as the vitality score progressively decreased as birth order increased in this group. Otherwise, the piglets born from ESP-sows were more resistant to the harmful effect of birth order as all the piglets born from this group had the same average vitality regardless of birth order. Consequently, the 17th and the 20th piglet born from ESP-sows had a higher vitality than the piglets with a similar birth order from CON. More studies are needed to understand the underlying mechanisms behind these findings as the present study lacks data to elucidate it clearly.

Consistently, vitality at birth has been considered as a key factor influencing colostrum intake (Declerck et al., 2017; Devillers et al., 2007; Quesnel et al., 2012). The higher vitality suggests an increased capacity to reach the udder and suckle in the piglets born later from ESP, which may explain the increased average colostrum intake per piglet in this group.

Table 5
Colostrum analyzed the composition of experimental sows.

	Treatments			
Analyzed Component	ESP	CON	SEM	*P-value*
N	12	12		–
Calcium (%)	0.05	0.05	0.01	0.9
Fat (%)	3.3	5.4	0.70	0.009
Phosphorus (%)	0.1	0.1	0.01	0.7
Lactose (%)	3.1	3.2	0.16	0.9
Ash (%)	0.5	0.5	0.07	0.9
CP (%)	16.0	15.9	0.83	0.7
Sodium (%)	714.0	726.0	28.30	0.8
DM (%)	24.7	24.3	0.87	0.6

ESP (n = 12): sows fed an energetic supplement at the onset of farrowing, and CON (n = 12): non-supplemented females.
All the percentages (%) are presented as weight/weight of the sample.
Statistical difference was set at P < 0.05.

Table 6
Litter growth performance throughout lactation of sows fed with (ESP) and without (CON) supplement.

Piglet weight, kg	Treatment		SEM	*P-value*
	ESP	CON		
At birth	1.3	1.3	0.05	0.20
24 h after birth	1.4	1.3	0.06	0.20
3 days of age	1.6	1.6	0.05	0.70
7 days of age	2.4	2.2	0.08	0.20
14 days of age	4.0	4.0	0.14	0.90
21 days of age	6.1	6.1	0.15	0.90

ESP (n = 95): sows fed an energetic supplement at the onset of farrowing, and CON (n = 85): non-supplemented females.
Statistical difference was set at $P < 0.05$.

Conclusion

Strategies to decrease farrowing duration aiming of reducing in stillbirth rate might not always be efficient in hyperprolific herds, especially in herds that do not have prolonged farrowing durations. The supplement used in the present study successfully supplied glucogenic substrate for uterine contractions, nevertheless, it might be more beneficial in herds where prolonged farrowing duration is an issue.

The findings of the study support the notion that feeding the energetic supplement at the onset of farrowing seems to be a reasonable strategy to reduce farrowing duration, as the longer inter-piglet birth interval is observed in the second piglet in the litter.

The improvements in vitality and colostrum intake observed in piglets born from sows that received the supplement suggest that they better endured the challenges of farrowing and adaptations to extra-uterine life. However, these positive effects were not associated with any difference in piglet growth throughout lactation.

Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.animal.2024.101104.

Ethics approval

This study was approved by the Committee on Ethics in Animal Use (CEUA) of the Agroceres Multimix under protocol n° 38.21 and co-validated by the CEUA of the School of Veterinary Medicine and Animal Science (FMVZ-USP), University of São Paulo, under protocol no. 1541030220.

Data and model availability statement

None of the data were deposited in an official repository. The dataset used and / or analyzed during the current study is available from the corresponding author 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.

Author ORCIDs

R.F. Carnevale: https://orcid.org/0000-0002-0722-6008.
B.B.D. Muro: https://orcid.org/0000-0003-3694-0881.
D.F. Leal: https://orcid.org/0000-0001-9205-2382.
L.K.S. Alves: https://orcid.org/0000-0002-9534-6121.
M.S. Monteiro: https://orcid.org/0000-0002-1949-6697.
N.A.C. Gomes: https://orcid.org/0000-0003-0758-9412.
F.N.A. Ferreira: https://orcid.org/0000-0002-2225-1674.
C.S.S. Neta: https://orcid.org/0000-0003-0468-8693.
T.T.N. Watanabe: https://orcid.org/0000-0002-9922-0235.
G.W. Almond: https://orcid.org/0000-0003-3210-6718.
C.A.P. Garbossa: https://orcid.org/0000-0003-3244-7184.

CRediT authorship contribution statement

R.F. Carnevale: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **B.B.D. Muro:** Writing – review & editing, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **D.F. Leal:** Writing – review & editing, Writing – original draft, Methodology, Data curation. **L.K.S. Alves:** Writing – review & editing, Methodology, Investigation. **M.S. Monteiro:** Writing – review & editing, Methodology, Formal analysis, Data curation. **N.A.C. Gomes:** Writing – review & editing, Investigation, Data curation. **F.A. Pereira:** Writing – review & editing, Resources, Project administration, Funding acquisition. **F.N.A. Ferreira:** Writing – review & editing, Investigation, Funding acquisition, Formal analysis. **C.S.S. Neta:** Writing – review & editing, Investigation, Funding acquisition. **T.T.N. Watanabe:** Writing – review & editing, Funding acquisition. **G.W. Almond:** Writing – review & editing, Project administration, Methodology, Conceptualization. **C.A.P. Garbossa:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of interest

The authors declare that they have no competing interests.

Acknowledgements

The author would like to acknowledge Agroceres Multimix for the partnership and all the veterinarians, field and laboratory personnel who participated in this study.

This is a manuscript derived from the following thesis: "Carnevale, R.F., 2022. Glycemia and farrowing traits in pigs: Exploring the association between energetic metabolism and farrowing traits in pigs. Master thesis, University of São Paulo, Pirassununga, São Paulo, Brazil."

Financial support statement

RFC is recipient of FAPESP fellowship (grant 2019/23320–7). BBDM is recipient of FAPESP fellowship (grant 2020/02731–6). CAPG is a FAPESP fellowship (2020/11016–9) and CNPq fellowship (303750/2021-9).

References

Alonso-Spilsbury, M., Mota-Rojas, D., Villanueva-García, D., Martínez-Burnes, J., Orozco, H., Ramírez-Necoechea, R., Mayagoitia, A.L., Trujillo, M.E., 2005. Perinatal asphyxia pathophysiology in pig and human: a review. Animal Reproduction Science 90, 1–30. https://doi.org/10.1016/j.anireprosci.2005.01.007.

Araújo, V. de O., de Oliveira, R.A., Vieira, M. de F.A., Silveira, H., Fonseca, L. da S., Alves, L.K.S., Guimarães, E.B.B., Schinckel, A.P., Garbossa, C.A.P., 2020. Bump feed for gestating sows is really necessary? Livestock Science 240, 104184. https://doi.org/10.1016/j.livsci.2020.104184.

Association of Official Analytical Chemists, 2005. Official Methods of the Association of Official Analytical Chemistry, 16th ed. AOAC, Arlington, WA, USA.

Baxter, E.M., Edwards, S.A., 2018. Piglet mortality and morbidity. In: Spinka, M. (Ed.), Advances in Pig Welfare. Elsevier, Duxford, UK, pp. 73–100. https://doi.org/10.1016/B978-0-08-101012-9.00003-4.

Björkman, S., Oliviero, C., Rajala-Schultz, P.J., Soede, N.M., Peltoniemi, O.A.T., 2017. The effect of litter size, parity and farrowing duration on placenta expulsion and retention in sows. Theriogenology 92, 36–44. https://doi.org/10.1016/j.theriogenology.2017.01.003.

Bruun, T.S., Eskildsen, M., Hojgaard, C.K., Nørskov, N.P., Knudsen, K.E.B., Theil, P.K., Feyera, T., 2023. Feeding level during the last week of gestation can influence performance of sows and their litters in the subsequent lactation. Journal of Animal Science 101, skad349. https://doi.org/10.1093/jas/skad349.

Carnevale, R.F., Muro, B.B., Pierozan, C.R., Monteiro, M.S., Leal, D.F., Poor, A.P., Alves, L.K., Gomes, N.A., Silva, C.A., Maes, D., Janssens, G.P., Almond, G.W., Garbossa, C. A., 2023. Peripheral glycemia and farrowing traits in pigs: an observational study. Livestock Science 270,. https://doi.org/10.1016/j.livsci.2023.105203 105203.

Cornelison, A.S., Karriker, L.A., Williams, N.H., Haberl, B.J., Stalder, K.J., Schulz, L.L., Patience, J.F., 2018. Impact of health challenges on pig growth performance, carcass characteristics, and net returns under commercial conditions. Translational Animal Science 2, 50–61. https://doi.org/10.1093/tas/txx005.

Declerck, I., Sarrazin, S., Dewulf, J., Maes, D., 2017. Sow and piglet factors determining variation of colostrum intake between and within litters. Animal 11, 1336–1343. https://doi.org/10.1017/S1751731117000131.

Devillers, N., Farmer, C., Le Dividich, J., Prunier, A., 2007. Variability of colostrum yield and colostrum intake in pigs. Animal 1, 1033–1041. https://doi.org/10.1017/S175173110700016X.

Edwards, L.E., Plush, K.J., Ralph, C.R., Morrison, R.S., Acharya, R.Y., Doyle, R.E., 2019. Enrichment with lucerne hay improves sow maternal behaviour and improves piglet survival. Animals 9, 558. https://doi.org/10.3390/ani9080558.

Farmer, C., Edwards, S.A., 2022. Review: Improving the performance of neonatal piglets. Animal 16,. https://doi.org/10.1016/j.animal.2021.100350 100350.

Feyera, T., Pedersen, T.F., Krogh, U., Foldager, L., Theil, P.K., 2018. Impact of sow energy status during farrowing on farrowing kinetics, frequency of stillborn piglets, and farrowing assistance. Journal of Animal Science 96, 2320–2331. https://doi.org/10.1093/jas/sky141.

Feyera, T., Skovmose, Sigrid J.W., Nielsen, S.E., Vodolazska, D., Bruun, T.S., Theil, P.K., 2021. Optimal feed level during the transition period to achieve faster farrowing and high colostrum yield in sows. Journal of Animal Science 99, skab040. https://doi.org/10.1093/jas/skab040.

Feyera, T., Theil, P.K., 2017. Energy and lysine requirements and balances of sows during transition and lactation: a factorial approach. Livestock Science 201, 50–57. https://doi.org/10.1016/j.livsci.2017.05.001.

Gourley, K.M., Swanson, A.J., Royall, R.Q., DeRouchey, J.M., Tokach, M.D., Dritz, S.S., Goodband, R.D., Hastad, C.W., Woodworth, J.C., 2020. Effects of timing and size of meals prior to farrowing on sow and litter performance. Translational Animal Science 4, 724–736. https://doi.org/10.1093/tas/txaa066.

Herpin, P., Le Dividich, J., Hulin, J.C., Fillaut, M., De Marco, F., Bertin, R., 1996. Effects of the level of asphyxia during delivery on viability at birth and early postnatal vitality of newborn pigs. Journal of Animal Science 74, 2067. https://doi.org/10.2527/1996.7492067x.

Lane, J.H., Eynon, L., 1923. Determination of reducing sugar by means of Fehling's solution with methylene blue as internal indicator. Journal of the Society of Chemical Industry 17, 32–37.

Langendijk, P., Bolhuis, J.E., Laurenssen, B.F.A., 2007. Effects of pre- and postnatal exposure to garlic and aniseed flavour on pre- and postweaning feed intake in pigs. Livestock Science 108, 284–287. https://doi.org/10.1016/j.livsci.2007.01.083.

Langendijk, P., Fleuren, M., van Hees, H., van Kempen, T., 2018. The course of parturition affects piglet condition at birth and survival and growth through the nursery phase. Animals 8, 60. https://doi.org/10.3390/ani8050060.

Langendijk, P., Plush, K., 2019. Parturition and its relationship with stillbirths and asphyxiated piglets. Animals 9, 885. https://doi.org/10.3390/ani9110885.

Leenhouwers, J.I., van der Lende, T., Knol, E.F., 1999. Analysis of stillbirth in different lines of pig. Livestock Production Science 57, 243–253. https://doi.org/10.1016/S0301-6226(98)00171-7.

Liu, Y., Zhou, Q., Theil, P.K., Fang, Z., Lin, Y., Xu, S., Feng, B., Zhuo, Y., Wu, F., Jiang, X., Zhao, X., Wu, D., Che, L., 2021. The differences in energy metabolism and redox status between sows with short and long farrowing duration. Animal 15,. https://doi.org/10.1016/j.animal.2021.100355 100355.

Maes, D.G.D., Janssens, G.P.J., Delputte, P., Lammertyn, A., de Kruif, A., 2004. Back fat measurements in sows from three commercial pig herds: relationship with reproductive efficiency and correlation with visual body condition scores. Livestock Production Science 91, 57–67. https://doi.org/10.1016/j.livprodsci.2004.06.015.

Martinez, C.H.G., Ravagnani, G.M., Muro, B.B.D., Mendonça, M.V., Passarelli, M.S., Nakasone, D.H., Carnevale, R.F., Strefezzi, R.F., Martins, S.M.M.K., Andrade, A.F.C., 2020. Dietary ractopamine supplementation of pregnant sows: what are the impacts on the neonate? Animal 14, 50–58. https://doi.org/10.1017/S1751731119001496.

Muns, V.R., Tummaruk, P., 2016. Management strategies in farrowing house to improve piglet pre-weaning survival and growth. The Thai Journal of Veterinary Medicine 46, 347–354.

Muro, B.B.D., Carnevale, R.F., Andretta, I., Leal, D.F., Monteiro, M.S., Poor, A.P., Almond, G.W., Garbossa, C.A.P., 2021. Effects of uterotonics on farrowing traits and piglet vitality: a systematic review and meta-analysis. Theriogenology 161, 151–160. https://doi.org/10.1016/j.theriogenology.2020.12.003.

Oliveira, R.A., Neves, J.S., Castro, D.S., Lopes, S.O., Santos, S.L., Silva, S.V.C., Araújo, V. O., Vieira, M.F.A., Muro, B.B.D., Leal, D.F., Carnevale, R.F., Almond, G., Garbossa, C. A.P., 2020. Supplying sows energy on the expected day of farrowing improves farrowing kinetics and newborn piglet performance in the first 24 h after birth. Animal 14, 2271–2276. https://doi.org/10.1017/S1751731120001317.

Oliviero, C., Heinonen, M., Valros, A., Peltoniemi, O., 2010. Environmental and sow-related factors affecting the duration of farrowing. Animal Reproduction Science 119, 85–91. https://doi.org/10.1016/j.anireprosci.2009.12.009.

Quesnel, H., Farmer, C., Devillers, N., 2012. Colostrum intake: influence on piglet performance and factors of variation. Livestock Science 146, 105–114. https://doi.org/10.1016/j.livsci.2012.03.010.

Regmi, P.R., van Kempen, T.A.T.G., Matte, J.J., Zijlstra, R.T., 2011. Starch with high amylose and low in vitro digestibility increases short-chain fatty acid absorption, reduces peak insulin secretion, and modulates incretin secretion in pigs. Journal of Nutrition 141, 398–405. https://doi.org/10.3945/jn.110.132449.

Serena, A., Jørgensen, H., Bach Knudsen, K.E., 2009. Absorption of carbohydrate-derived nutrients in sows as influenced by types and contents of dietary fiber. Journal of Animal Science 87, 136–147. https://doi.org/10.2527/jas.2007-0714.

Theil, P.K., Jørgensen, H., Serena, A., Hendrickson, J., Bach Knudsen, K.E., 2011. Products deriving from microbial fermentation are linked to insulinaemic response in pigs fed breads prepared from whole-wheat grain and wheat and rye ingredients. British Journal of Nutrition 105, 373–383. https://doi.org/10.1017/S0007114510003715.

Theil, P.K., Flummer, C., Hurley, W.L., Kristensen, N.B., Labouriau, R.L., Sørensen, M. T., 2014. Mechanistic model to predict colostrum intake based on deuterium oxide dilution technique data and impact of gestation and prefarrowing diets on piglet intake and sow yield of colostrum. Journal of Animal Science 92, 5507–5519. https://doi.org/10.2527/jas.2014-7841.

Vallet, J.L., Miles, J.R., Rempel, L.A., 2013. Effect of creatine supplementation during the last week of gestation on birth intervals, stillbirth, and preweaning mortality in pigs. Journal of Animal Science 91, 2122–2132. https://doi.org/10.2527/jas.2012-5610.

van den Bosch, M., Soede, N., Kemp, B., van den Brand, H., 2023. Sow nutrition, uterine contractions, and placental blood flow during the peri-partum period and short-term effects on offspring: a review. Animals 13, 910. https://doi.org/10.3390/ani13050910.

van Dijk, A.J., van Rens, B.T.T.M., van der Lende, T., Taverne, M.A.M., 2005. Factors affecting duration of the expulsive stage of parturition and piglet birth intervals in sows with uncomplicated, spontaneous farrowings. Theriogenology 64, 1573–1590. https://doi.org/10.1016/j.theriogenology.2005.03.017.

van Dijk, A.J., van Loon, J.P.A.M., Taverne, M.A.M., Jonker, F.H., 2008. Umbilical cord clamping in term piglets: a useful model to study perinatal asphyxia? Theriogenology 70, 662–674. https://doi.org/10.1016/j.theriogenology.2008.04.044.

van Kempen, T., 2008. Supplements to facilitate parturition and reduce perinatal mortality in pigs. Recent Advances in Animal Nutrition 2007, 317–330. https://doi.org/10.5661/recadv-07-317.

Wegner, K., Lambertz, C., Das, G., Reiner, G., Gauly, M., 2016. Effects of temperature and temperature-humidity index on the reproductive performance of sows during summer months under a temperate climate. Animal Science Journal 87, 1334–1339. https://doi.org/10.1111/asj.12569.

Yang, Y., Hu, C.J., Zhao, X., Xiao, K., Deng, M., Zhang, L., Qiu, X., Deng, J., Yin, Y., Tan, C., 2019. Dietary energy sources during late gestation and lactation of sows: effects on performance, glucolipid metabolism, oxidative status of sows, and their offspring. Journal of Animal Science 97, 4608–4618. https://doi.org/10.1093/jas/skz297.