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Effects of increased lysine and energy feeding duration prior to parturition on sow and litter performance, piglet survival, and colostrum quality

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Abstract

A total of 467 sows were used to evaluate the effect of feeding duration of increased lysine (**Lys**) and metabolizable energy (**ME**) prior to farrowing on sow and litter performance, piglet survival, and colostrum quality. Sows were blocked by body weight (**BW**) and parity category on day 106 of gestation and allotted to one of three dietary regimens starting on day 107 of gestation: 1) Control: 2.0 kg/d gestation feed (12.5 g standardized ileal digestible [**SID**] Lys and 6.5 Mcal ME) until day 113 of gestation, then 2.7 kg/d lactation feed (28 g SID Lys and 9.4 Mcal ME) until parturition; 2) 2.0 kg/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until day 113 of gestation, then 3.8 kg/d lactation feed (40 g SID Lys and 13.3 Mcal ME) until parturition; or 3) 3.8 kg/d lactation feed (40 g SID Lys and 13.3 Mcal ME) until parturition. Data were analyzed for treatment within parity effects using the GLIMMIX procedure of SAS. Increasing the duration of feeding additional Lys and ME increased ($P < 0.05$) sow weight gain from day 106 to 113. Sow backfat gain from day 106 to 113 of gestation increased ($P < 0.05$) in gilts and sows fed 3.8 kg/d of the lactation diet starting on day 107 vs. the control regimen. Average total born and born alive piglet birth weight (**BiWt**) were greater ($P < 0.05$) in gilts fed 3.8 kg/d lactation diet starting on day 107 or 113 vs. control, with no evidence ($P > 0.05$) for the difference in piglet BiWt in sows or weaning weight in gilts and sows. Piglet mortality after cross-fostering to weaning was decreased ($P < 0.05$) in sows fed 3.8 kg/d lactation diet starting on day 113 vs. control or increased lactation diet starting on day 107 but not in gilts. Litter gain from cross-foster to weaning was decreased ($P < 0.05$) in gilts fed 3.8 kg/d lactation diet starting on day 107 compared with control, with no evidence for difference in sows. Colostrum immunoglobulin G was increased ($P < 0.05$) in gilts and sows fed 3.8 kg/d of the lactation diet starting on day 113 compared with control. There was no evidence that dietary regimen influenced ($P > 0.05$) piglet colostrum intake or colostrum yield. There was also no evidence for difference ($P > 0.05$) among regimens in wean-to-estrus interval, subsequent farrowing rate, or subsequent litter characteristics. In conclusion, feeding increased Lys and ME prior to farrowing increased BW and backfat. Feeding increased Lys and ME when gilts were moved into the farrowing room increased BiWt, but reduced litter growth to weaning, with little evidence that sow performance was influenced in this study.

Key words: colostrum, energy, lactation, lysine, reproduction, transition sow

Abbreviations

AA	amino acids
BiWt	birth weight
BW	body weight
IgG	immunoglobulin G
Lys	lysine
ME	metabolizable energy
NE	net energy
SID	standardized ileal digestible

Introduction

In recent years, a large emphasis has been placed on understanding the requirements of high-producing sows (Tokach et al., 2019). While several studies have been conducted to evaluate changing nutrient requirements in late gestation (day 90 to parturition) and lactation, few studies have focused on the few days immediately before farrowing. This transition period has been defined as the last 10 d of gestation to the first 10 d of lactation (Theil, 2015), with studies involving transition diets starting to be fed between days 104 and 109 of gestation (Loisel et al., 2014; Feyera et al., 2017; Garrison et al., 2017).

Fetal growth rate increases exponentially in late gestation (McPherson et al., 2004), and, in the last 10 d prior to parturition, it is estimated that fetal growth (22.7%), mammary growth (16.8%), and colostrum production (16.1%) represent the majority of the total required standardized ileal digestible (**SID**) lysine (Feyera and Theil, 2017). Additionally, the majority (66%) of the sow metabolizable energy (**ME**) requirement is derived from sow maintenance, resulting in ME and SID Lys requirements increasing by 60% and 149% from day 104 to115 of gestation, respectively (Feyera and Theil, 2017).

Based on a factorial approach, Feyera and Theil (2017) predicted that the ME and SID Lys requirement on the last day of gestation is approximately 13.3 Mcal/d ME and 35 g/d SID Lys, which is a significant increase in energy and Lys required compared with what is typically provided in a corn and soybean meal-based gestation diet. Goncalves et al. (2016a) analyzed the results of multiple trials providing increased feed allowance from day 90 to farrowing and observed an average concentration of 20 g/d of SID Lys supplied to sows, which would be 15 g/d less than the predicted requirement during the final 7 d of gestation (Feyera and Theil, 2017). However, this review (Goncalves et al., 2016a) observed only modest increases, if any, in piglet birth weight (**BiWt**). Dourmad et al. (2008) suggested that late gestation ME intake is typically below the level required for maximum nitrogen retention. Therefore, in the last few days before parturition, the sow may be in a negative Lys and energy balance as she partitions an exponentially increasing amount of nutrients toward rapid fetal growth (McPherson et al., 2004) and colostrum production (Feyera and Theil, 2017).

Previous trials conducted to evaluate different diet regimens for transition sows have been conducted mostly in small research herds, thus there is a need to confirm these previous findings in larger commercial farms. Thus, the objective of the current experiment was to determine the impact of different feeding durations of increased Lys and energy immediately prior to farrowing on colostrum production, sow and litter performance, and piglet survival under commercial conditions.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. This experiment was conducted on a commercial 3,000-sow farm in southern Minnesota during summer 2018 (Christensen Farms, Sleepy Eye, MN). The facilities were environmentally controlled with mechanical ventilation.

A total of 467 mixed parity sows (Fast Large white × PIC Landrace) were used from day 106 of gestation until weaning. On day 106 of gestation, sows were weighed, blocked by body weight (**BW**) within parity category (gilts and sows), and allotted to one of three dietary treatments. Treatments were fed starting on day 107 of gestation and consisted of: 1) Control: 2.0 kg/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) fed until day 113 of gestation, then 2.7 kg/d lactation feed (28 g SID Lys and 9.4 Mcal ME) offered until parturition; 2) 2.0 kg/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) fed until day 113 of gestation, then 3.8 kg/d lactation feed (40 g SID Lys and 13.3 Mcal ME) offered until parturition; or 3) 3.8 kg/d lactation feed (40 g SID Lys and 13.3 Mcal ME) offered from day 107 of gestation until parturition. Diets were formulated and fed to meet or exceed all other nutrient requirements (NRC, 2012) and were manufactured in Sleepy Eye, MN (Table 1). Sows were hand-fed their respective dietary treatments from day 107 of gestation until parturition, at which point they were fed the lactation diet to approximate ad libitum feeding by filling feed hoppers twice daily until weaning. These lactation feeders contained a rod that sows manipulated to dispense feed whenever activated. Feed samples of each diet were collected twice each week from the feeders at the farm. Samples were pooled and used for chemical analysis.

Females were moved from the gestation facility to a farrowing room (approximately day 113 of gestation), weighed, and backfat thickness measured. All backfat measurements were performed by the same person, using a Renco Lean Meter (S.E.C. Repro Inc., Quebec, Canada) at the P2 position (last rib, 6 to 8 cm from the midline) on each side of the sow and then taking an average of the two measurements. Each farrowing stall (1.5 × 2.1 m total, with 0.6 × 2.1 m for sows) contained a nipple waterer and feeder for the sow and also a rubber mat with a heat lamp for the piglets. Sows were induced (2cc, Lutalyse, Zoetis Inc., Kalamazoo, MI) on the afternoon of day 115 of gestation if parturition had not started. Farrowing surveillance occurred daily from 0300 to 2400 hours. Only litters born during the surveillance period were included to ensure accurate classification of born alive, stillborn, and mummified fetuses. Farrowing assistance was given to sows if the presence of a wet pig had not occurred for 45 min. For analysis, mummified fetuses (220 total) were excluded from the total born count. Total born was calculated as the sum of born alive and stillborn pigs. Survivability to 24 h was calculated as: [total born − (stillborn + 24 h mortality)]/total born.

During farrowing, the time each piglet was born was recorded, the umbilical cord was cut to 10 cm, the piglet was dried using desiccant and paper towels, identified with an ear tag, and weighed. Stillborn pigs were also weighed and birth time recorded. Within 3 h from the initiation of parturition, a 50-mL sample of colostrum was collected from multiple teats and the number of functional teats was recorded. Colostrum samples were split into two subsamples: 15 mL for colostrum immunoglobulin G (**IgG**) analysis and 35 mL for nutrient analysis (preserved with an 18% Bronopol pellet). Samples were stored at −20 °C until analysis.

At 24 h after the birth of the first pig, piglets were individually weighed to calculate the colostrum intake. Colostrum intake was calculated using the equation:

$$\text{colostrum intake} = -106 + 2.26\ \text{WG} + 200\ \text{BWB} + 0.111\ \text{D} \quad 1{,}414\ \text{WG/D} + 0.0182\ \text{WG/BWB}$$

Table 1. Diet composition (as-fed)[1]

Item	Gestation	Lactation
Ingredient, %		
Corn	45.29	48.12
Soybean meal	4.52	25.14
DDGS[2]	12.20	5.00
Bakery meal	10.00	15.00
Soybean hulls	12.20	—
Corn oil	1.23	2.90
Dicalcium phosphate, 18.5% P	1.88	1.86
Limestone	0.66	0.61
Lysine-HCl	0.26	0.34
Salt	0.27	0.23
L-Threonine	0.06	0.12
DL-Methionine	0.02	0.06
Vitamin and mineral premix[3]	0.16	0.16
Choline chloride, 70%	0.13	0.13
SalCurb[4]	0.33	0.33
Total	100	100
Calculated analysis		
SID AA, %		
Lysine	0.62	1.06
Methionine:lysine	36	29
Methionine and cysteine:lysine	54	54
Threonine:lysine	64	64
Tryptophan:lysine	18	18
Valine:lysine	70	70
Isoleucine:lysine	63	63
Total lysine, %	0.77	1.21
Crude protein, %	14.0	18.3
ME, kcal/kg	3,212	3,593
NE, kcal/kg	2,300	2,520
Calcium, %	0.85	0.85
Phosphorus, %	0.74	0.72
Chemical analysis[5]		
Dry matter	89.1	88.9
Crude protein	14.9	19.0
Calcium	0.90	0.92
Phosphorus	0.73	0.71

[1]Diets were fed according to the regimen as follows: 1) 2.0 kg/d gestation feed until day 113 of gestation, then 2.7 kg/d lactation feed until parturition; 2) 2.0 kg/d gestation feed until day 113 of gestation, then 3.8 kg/d lactation feed until parturition; and 3) 3.8 kg/d lactation feed from day 107 of gestation until parturition.
[2]Dried distillers' grain with solubles.
[3]Provided per kg complete feed: 10,000 IU vitamin A; 500 IU vitamin D3; 50 µg 25(OH)D_3 (Hy-D; DSM); 100 IU vitamin E; 0.04 mg vitamin B12; 10 mg vitamin B2; 45 mg niacin; 35 mg D-pantothenic acid; 4.5 mg menadione; 1.35 mg folic acid, 2.2 mg thiamine; 3.3 mg pyridoxine; 0.22 mg biotin; 0.30 mg selenium; 20 mg Cu from copper chloride; 100 mg Fe from iron sulfate; 130 mg Zn from zinc sulfate; 50 mg Mg from Mg oxide; 1.13 mg I from I sulfate.
[4]Kemin Industries Inc. (Des Moines, IA).
[5]Diet samples were collected twice weekly from the feeders (4 or 8 wk for gestation and lactation, respectively). Nutrient analysis was conducted in duplicate on the weekly pooled samples (Ward Laboratories, Kearney, NE).

The WG represents 24 h piglet weight gain in grams, D is the duration of colostrum suckling in minutes, and BWB is body weight at birth in kilograms as described by Theil et al. (2014). Colostrum yield was calculated as the sum of the colostrum intake of the pigs in the litter. If a piglet died before 24 h, the assumption was no colostrum intake by that piglet.

After 24 h, pigs were cross-fostered within treatment to equalize litter size. All piglet mortalities were weighed and the date recorded. Fall-behind piglets, removed due to weight loss or injury between days 3 and 10 of age, were weighed and moved off test to a nurse sow. At weaning (day 20 ± 3), all piglets were individually weighed to measure piglet and litter gain during lactation. Litter gain was calculated as: litter weaning weight – litter weight after cross foster.

At weaning, sows were weighed, backfat measurements recorded, then moved to gestation stalls, and checked twice daily for signs of estrus using a boar and back pressure test. Wean-to-first service interval and day 30 conception rate were collected on 419 of the 423 sows that were weaned. Subsequent litter characteristics were collected on 363 females.

Chemical analysis

Four samples (one per week) of gestation diet and eight samples (one per week) of lactation diet from within the weekly pooled samples were sent to a commercial laboratory (Ward Laboratories, Kearney, NE) and analyzed in duplicate for crude protein (method 990.03; AOAC International, 2006), calcium (Campbell and Plank, 1991; Kovar, 2003), and phosphorus (Campbell and Plank, 1991; Kovar, 2003).

One colostrum sample (35 mL) per sow was sent to a commercial laboratory (Stearns DHIA Lab, Sauk Centre, MN) and analyzed in duplicate for fat, protein, lactose, and total solids (Combi-Foss milk analyzer, Foss Analytics, Denmark). One colostrum sample (15 mL) per sow was thawed at room temperature, vortexed, diluted to 1:1,000,000, and analyzed in duplicate for IgG concentration using the Porcine IgG ELISA Quantitation Kit (Bethyl Laboratories, Montgomery, TX).

Statistical analysis

Data were analyzed using a generalized linear mixed model where dietary regimen within parity category (gilt or sow) was a fixed effect and block was a random effect. Statistical models were fit using the GLIMMIX procedure of SAS (Version 9.4, SAS Institute, Inc., Cary, NC). During lactation, 44 sows were removed from the study due to becoming a nurse sow ($n = 24$), poor health ($n = 11$), or poor milking ability ($n = 9$). These sows were not included in the analysis for litter performance after 24 h.

Sow BW, backfat depth, litter weights, mean piglet BWs, litter gains, colostrum quality (fat, protein, lactose, and solids), colostrum yield, and colostrum intake were fit using a normal distribution. Total born, litter counts, and wean-to-estrus interval were fit using a negative binomial distribution. Percentage born alive, stillborn, fall-behind pigs, survivability, mortality, estrus by day 7, and subsequent farrowing rate were fit using a binomial distribution. Colostrum IgG concentration was analyzed using a log transformation.

Covariates were used if they significantly improved the model fit and were biologically consistent. Residuals and the Bayesian Information Criterion were used as an indication of improved model fit. Total born was used as a covariate for total born litter weight and mean (**BiWt**). Born alive was used as a covariate for born alive and 24 h litter weights and mean piglet born alive birth and 24 h weights. Pig-to-teat ratio was used as a covariate for 24 h litter gain, colostrum yield, and intake. Litter size after cross foster was used as a covariate for litter weight and piglet weight after cross-fostering and at weaning.

Results and Discussion

Sow BW change

There was no evidence of difference ($P > 0.05$; Table 2) in sow BW and backfat depth at allotment and gestation length across regimens within the parity category which validates

Table 2. Increased lysine and energy feeding duration prior to parturition on sow performance within parity catergory[1]

	Gilts				Sows			
Response	Control	Day 113	Day 107	SEM	Control	Day 113	Day 107	SEM
Farrowing count, *n*	45	46	45	—	111	108	112	—
Gestation length, d	115.7	115.7	115.8	0.12	115.7	115.8	115.8	0.08
Sow BW, kg								
Day 106	224.4	224.2	224.9	3.37	276.7	276.2	276.2	2.19
Loading[2,3]	226.9[b]	227.9[ab]	233.0[a]	3.37	279.8[b]	279.7[b]	284.9[a]	2.20
Post-farrow[4]	203.1	203.9	209.2	2.96	251.7	252.5	256.6	1.92
Weaning	182.0	181.8	184.8	3.89	231.3	232.9	235.9	2.65
Sow weight change, kg								
Day 106 to loading[5]	2.1	4.0	7.1	0.87	2.4	3.4	8.8	0.56
Loading[2] to weaning	−44.1	−46.5	−49.5	2.68	−47.5	−46.4	−49.5	1.84
Post farrow-weaning	−20.4	−22.5	−25.5	2.64	−19.5	−19.5	−20.7	1.80
Day 106 to weaning	−41.9	−42.5	−42.0	2.8	−44.9	−43.0	−40.3	1.91
Sow backfat, mm								
Day 106	20.0	19.0	20.4	0.55	18.1	18.0	17.7	0.35
Loading[2,3]	20.5[ab]	19.8[b]	21.3[a]	0.58	18.3	18.5	18.4	0.37
Weaning[5]	12.7	12.8	14.2	0.50	13.7	13.4	13.9	0.34
Sow backfat change, mm								
Day 106 to loading[2,6]	0.4	0.7	0.9	0.23	0.2	0.5	0.6	0.15
Loading[2] to weaning	−7.9	−6.9	−7.4	0.58	−4.6	−4.8	−4.5	0.38
Day 106 to weaning	−7.2	−6.2	−6.3	0.56	−4.4	−4.4	−3.9	0.37

[1]A total of 467 sows were used from day 106 of gestation until weaning. Sows were weighed, blocked by BW and parity category, and allotted to the regimen on day 106 of gestation. Regimens consisted of: 1) 2.0 kg/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until day 113 of gestation, then 2.7 kg/d lactation feed (28 g SID Lys and 9.4 Mcal ME) until parturition; 2) 2.0 kg/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until day 113 of gestation, then 3.8 kg/d lactation feed (40 g SID Lys and 13.3 Mcal ME) until parturition; or 3) 3.8 kg/d lactation feed (40 g SID Lys and 13.3 Mcal ME) from day 107 of gestation until parturition. Movement from gestation to farrowing occurred at day 113 (± 2 d) of gestation. Weaning occurred at day 18 to 24 of lactation.
[2]Time of movement from gestation to farrowing room (day 113 ± 2).
[3]Significant regimen within parity differences. Values within the parity category without a common superscript differ ($P < 0.05$).
[4]Main effect of regimen ($P < 0.05$).
[5]Main effect: Control vs. day 107, day 107 vs. 113 ($P < 0.05$).
[6]Main effect: Control vs. day 113 ($P < 0.05$).

the allotment to treatment. At the time, sows and gilts were moved to the farrowing room (day 113 ± 2), a regimen within parity category effect was observed where gilts fed 3.8 kg/d lactation diet starting on day 107 were 6.1 kg heavier ($P < 0.05$) than control gilts, with gilts that received 3.8 kg/d lactation diet starting on day 113 intermediate. Sows fed 3.8 kg/d lactation diet starting on day 107 were heavier ($P < 0.05$) than sows fed control or those that received 3.8 kg/d lactation diet starting on day 113. As a result, a main effect of feeding regimen was observed for sow weight change from allotment to movement to the farrowing rooms where gilts and sows fed 3.8 kg/d lactation diet starting on day 107 gained more weight ($P < 0.05$) than females that received 3.8 kg/d lactation diet starting on day 113, and females fed either regimen gained more weight than control-fed gilts or sows. This was expected due to the increased SID Lys and energy provided to females beginning at day 107 or 113 compared with the control feeding regimen. Previous studies that have evaluated increased feeding strategies starting on day 90 of gestation suggested that an additional 16.6 g/d SID Lys and 9.6 Mcal/d ME resulted in an additional 6.9 kg of BW gain (Goncalves et al., 2016a). While the dietary regimens in the current study would have been fed for a shorter duration, the much higher concentration of SID Lys (40 g/d) and ME intake (13.3 Mcal/d) resulted in similar BW gain as those where feed intake was increased from day 90 of gestation to farrowing (Yang et al., 2009; Mallmann et al., 2018).

There was no evidence for difference ($P > 0.05$) in sow BW at weaning or sow weight loss from movement to the farrowing rooms to weaning, regardless of dietary regimen. However, there was numerically greater BW loss during lactation in females that received 3.8 kg/d lactation diet starting on day 107 compared with control-fed females. Additionally, there was no evidence for difference ($P > 0.05$) in female BW change from allotment to weaning, indicating that the additional weight gain observed peripartum was subsequently lost during the lactation period. The BW loss observed could be due in part to reduced feed intake by females that were supplied 3.8 kg/d lactation diet starting on day 107; however, individual lactation feed intake was not collected in our study to confirm. Previous studies have shown that increased sow feed allowance in late gestation increases backfat gain prior to parturition which consequently leads to decreased feed intake and increased BW loss during the lactation period (Weldon et al., 1994; Koketsu et al., 1996; Mallmann et al., 2018)

Sow backfat

Backfat thickness at the time of movement into the farrowing house was increased ($P < 0.05$) in gilts that received lactation diet starting on day 107 compared with those starting on day 113, with control gilts intermediate. There was no evidence for difference in backfat thickness in sows at the time of movement from gestation to the farrowing room. A main effect of feeding regimen on backfat change from allotment to movement from gestation to the farrowing room was observed where females that received 3.8 kg/d lactation diet starting on day 107 had increased ($P < 0.05$) backfat gain compared with control females, but this change was small (0.5 mm). Similarly, increased backfat was observed when SID Lys (Yang et al., 2009) or gestation feed amount (Mallmann et al., 2019) was increased from day 90 to 112 in females. The NRC (2012) suggests that if the ME requirement for body maintenance, fetal growth, and maternal body protein are not met, sows will mobilize body lipid stores. The present study demonstrates that 1) the ME requirement for maintenance and fetal growth was met by feeding the control regimen because backfat change was positive from day 106 to movement to farrowing room and 2) the increased nutrient supply that resulted in increased BW was partially allocated toward sow body fat, regardless of parity.

There was no evidence for difference ($P > 0.05$) in backfat loss from the time of sow entry into the farrowing rooms until weaning. As a result, a main effect of regimen was observed for sow backfat thickness at weaning, where gilts and sows that received lactation diet starting on day 107 had increased ($P < 0.05$) backfat compared with the control or those that received 3.8 kg/d lactation diet starting on day 113. This agrees with previous studies, where increasing prepartum feed up to 3.3 kg/d (21 g SID Lys and 19.8 Mcal ME) from day 90 to farrowing in gilts resulted in increased backfat at day 112 of gestation and at weaning compared with females restricted to 1.7 kg/d gestation feed (Mallmann et al., 2019). Similarly, Cools et al. (2014) observed decreased backfat mobilization from day 104 to weaning when sows consumed feed ad libitum compared with restricted intake pre-farrowing. These results demonstrate that the additional backfat gained peripartum from increased feed intake prior to farrowing did not result in increased backfat loss during lactation. Rather, additional feed in the peripartum period resulted in increased backfat thickness at weaning compared with females restricted fed in the peripartum.

Litter weight, average piglet weight, and litter gain

There was a regimen within parity effect for total born litter weight, born alive litter weight, and 24 h litter weight, where gilts fed 3.8 kg/d lactation diet starting on day 113 or day 107 had heavier ($P < 0.05$; Table 3) litters compared with control gilts. Sows that received 3.8 kg/d lactation diet starting on day 107 had heavier ($P < 0.05$) total born and born alive litters at birth compared with sows fed 3.8 kg/d lactation diet starting on day 113, and control sows were intermediate.

A regimen within parity effect was observed for mean piglet BW for total born and born alive piglets, where gilts fed 3.8 kg/d lactation diet starting on day 107 or 113 had heavier ($P < 0.05$) piglets compared with control gilts, with no regimen difference for average piglet BiWt in piglets from sow litters. The literature regarding additional Lys and energy fed to gilts varies in the degree of response. Amdi et al. (2014) observed heavier piglet BiWts from fat gilts (19 mm) compared with thin gilts (14 mm) which had been restricted to a lower Lys and energy diet during gestation. Yang et al. (2009) observed increased piglet BiWt (100 g) from gilts fed increased total Lys (0.6% vs. 0.8%) starting on day 80 of gestation, whereas Goncalves et al. (2016b) observed a modest increase (28 g) in piglet BiWt from gilts fed 20 g SID Lys and 6.5 Mcal net energy (**NE**) from day 90 of gestation, compared with gilts fed 4.5 Mcal NE. In the current study, the much higher level of amino acids (**AA**) and energy (40 g/d SID Lys and 13.3 Mcal ME) combined may have allowed additional fetal growth to occur beyond what previous studies have observed. In fact,

Table 3. Increased lysine and energy feeding duration prior to parturition on litter performance to 24 h within parity category[1]

	Gilts				Sows			
Response	Control	Day 113	Day 107	SEM	Control	Day 113	Day 107	SEM
Litter weight, kg								
Total born[2], 0 h	19.0[b]	20.0[a]	20.0[a]	0.38	21.5[ab]	21.2[b]	22.0[a]	0.24
Born alive[2], 0 h	16.7[b]	18.0[a]	17.8[a]	0.31	20.4[ab]	20.2[b]	21.0[a]	0.24
24 h[2]	17.5[b]	18.7[a]	18.4[ab]	0.36	20.8	20.8	21.5	0.27
Mean piglet BW, g								
Total born[2], 0 h	1,289[b]	1,362[a]	1,356[a]	26.3	1,479	1,507	1,463	16.8
Born alive[2], 0 h	1,308[b]	1,403[a]	1,388[a]	23.7	1,470	1,458	1,508	18.1
24 h	1,435	1,503	1,489	25.4	1,586	1,585	1,618	18.6
Litter gain 0 to 24 h of live pigs, kg	1.28	1.07	1.07	0.171	1.23	1.40	1.17	0.095
Litter gain[3], kg	0.81	0.54	0.56	0.247	0.33	0.74	0.42	0.161
Total born BiWt CV, %	22.2	19.3	22.0	1.29	23.7	23.0	23.7	0.84
Born alive BiWt CV[2], %	18.4[b]	16.1[a]	16.4[b]	0.83	20.0	19.4	19.9	0.53
Litter size at birth								
Total born, *n*	13.9	14.1	13.6	0.44	15.4	15.3	14.8	0.28
Born alive, %	92.8	93.9	94.3	1.03	92.8	93.1	94.0	0.71
Stillborn, %	7.3	6.1	5.7	1.14	7.2	6.9	6.0	0.70
Litter size at 24 h, *n*	12.3	12.8	12.3	0.52	13.5	13.1	13.7	0.35
Survival from birth to 24 h[4], %	96.0	97.1	96.6	0.86	95.0	95.3	96.1	0.59
Survivability to 24 h[5], %	89.2	91.1	91.4	1.21	88.3	89.1	90.5	0.87

[1]A total of 467 sows were used from day 106 of gestation until weaning. Sows were weighed, blocked by BW and parity category, and allotted to the regimen on day 106 of gestation. Regimens consisted of: 1) Control: 2.0 kg/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until day 113 of gestation, then 2.7 kg/d lactation feed (28 g SID Lys and 9.4 Mcal ME) until parturition; 2) 2.0 kg/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until day 113 of gestation, then 3.8 kg/d lactation feed (40 g SID Lys and 13.3 Mcal ME) until parturition; or 3) 3.8 kg/d lactation feed (40 g SID Lys and 13.3 Mcal ME) from day 107 of gestation until parturition. Movement from gestation to farrowing occurred at day 113 (± 2 d) of gestation. Weaning occurred at day 18 to 24 of lactation.
[2]Significant regimen within parity differences. Values within parity category without a common superscript differ ($P < 0.05$).
[3]Litter gain = (litter weight at 24 h) – (born alive litter BiWt).
[4]Survival from birth to 24 h = litter size at 24 h/ born alive.
[5]Survivability to 24 h = (total born-(stillborn +24h mortality))/total born.

the additional ME intake may have allowed for gilts to be closer to the energy level required for maximum nitrogen retention in conceptus and maternal tissues (Dourmad et al., 2008).

There was no evidence ($P > 0.05$) for the difference in average piglet BiWt in sow litters. Similar to the literature, increasing Lys and energy resulted in little or no improvement in piglet BiWt from multiparous sows (Goncalves et al., 2016b; Mallmann et al., 2018; Wiegert, 2019). In a review, Goncalves et al. (2016a) summarized that a 1 kg/d increased feed allowance from day 90 of gestation modestly (+30 g) increased piglet BiWt. These results demonstrate that control regimen dietary intake of Lys and energy prior to farrowing were adequate for fetal growth in sows given the level of productivity. The difference in piglet BiWt response of regimen between gilts and sows may be due to the extra SID Lys and energy above normal estimated requirements satisfying gilt maternal protein deposition, maintenance, and fetal growth. Older parity sows (P4+) have a flatter slope for maternal protein deposition (NRC, 2012) and additional energy consumed does not appear to be partitioned toward fetal growth despite an increase in sow BW. Additionally, the body condition of sows when moved (day 113) to the farrowing room (18 mm) suggests that our sows may not have been at a body condition to respond to increased Lys and energy.

Born alive BiWt coefficient of variation (CV) was lower ($P < 0.05$) in gilts fed 3.8 kg/d lactation diet starting on day 113 compared with those fed the control regimen. This demonstrates less variation in BiWt in gilts that were fed additional SID Lys and energy for 3 d prior to farrowing. However, Mallmann et al. (2019) observed no evidence for difference in gilt litter BiWt CV when fed 21 g SID Lys and 10.8 Mcal ME for 30 d during late gestation. This difference may be due to the current study feeding almost twice the SID Lys (40 g/d) for a shorter period than in the study by Mallmann et al. (2019), allowing a reduction in BiWt CV to be observed. Furthermore, in sows, there was no evidence for difference ($P > 0.05$) in BiWt CV in piglets, which is in agreement with previous literature (Craig et al., 2017).

Piglets were cross-fostered up to 48 h within dietary regimens to equalize litter size (Table 4). Litter weight, litter count, and average pig BW after cross-fostering were similar ($P > 0.05$) across dietary regimens. There was no evidence for difference ($P > 0.05$) in litter weight, individual piglet BW, or litter count at weaning regardless of dietary regimen. However, litter gain from 48 h to weaning was decreased ($P < 0.05$) in gilts that received 3.8 kg/d lactation diet starting on day 107 compared with the control fed gilts, with no evidence for difference in sows. This was an unexpected result because earlier observational studies (Bergstrom, 2011; Douglas et. al., 2013) suggested that an increase in piglet BiWt also results in an increase in piglet weaning weight. One potential explanation for the reduction in litter gain in the current study is that increased weight gain of sows prior to farrowing may have had a negative effect on lactation feed intake, which resulted in less milk production and consequently reduced piglet growth. It is documented that reduced or restricted feed intake during lactation results in reduced litter gain and weaning weights compared with a high lactation feed intake (Craig et al., 2017). Several studies have observed that increased BW and backfat gain prior to parturition resulted in decreased voluntary feed intake during lactation (Weldon et al., 1994; Mallmann et al., 2018) which could

Table 4. Increased lysine and energy feeding duration prior to parturition on litter performance to weaning within parity category[1]

	Gilts				Sows			
Response	Control	Day 113	Day107	SEM	Control	Day 113	Day 107	SEM
Litters, *n*	42	43	41	—	99	98	100	—
Litter weight, kg								
After cross foster[2]	19.8	20.2	20.5	0.39	20.9	21.4	21.6	0.33
Weaning[5]	73.2	71.6	70.4	1.55	76.2	78.3	77.4	1.20
Average piglet BW, kg								
After cross foster[2]	1.48	1.52	1.54	0.029	1.56	1.60	1.61	0.025
Weaning[5]	5.98	6.00	5.80	0.105	6.57	6.54	6.56	0.082
Litter gain[3,4,5], kg	54.0[a]	51.5[ab]	49.7[b]	1.61	55.2	57.0	55.7	1.05
Litter count, *n*								
After cross foster[2]	13.3	13.5	13.3	0.56	13.6	13.2	13.7	0.36
Weaning	12.3	12.1	12.2	0.54	11.7	11.9	11.9	0.34
Fallbacks[6], %	2.9	2.9	2.4	0.66	5.3	3.7	4.9	0.63
Mortality[4,7], %	5.0	7.5	5.1	1.14	8.1[a]	5.4[b]	7.1[ab]	0.79
Weaned[4,8], %	92.4	90.2	92.0	1.33	86.6[b]	90.9[a]	88.3[b]	1.06
Wean age, d	20.8	20.9	20.7	0.23	20.8	20.6	20.6	0.15

[1]A total of 423 sows were weaned from an initial 472 sows that farrowed. Sows were removed due to poor milking, health challenge, becoming nurse sows. Pigs stayed with birth sow until 24 h, then were cross-fostered within regimen to equalize litter size. Regimens consisted of: 1) Control: 2.0 kg/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until day 113 of gestation, then 2.7 kg/d lactation feed (28 g SID Lys and 9.4 Mcal ME) until parturition; 2) 2.0 kg/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until day 113 of gestation, then 3.8 kg/d lactation feed (40 g SID Lys and 13.3 Mcal ME) until parturition; or 3) 3.8 kg/d lactation feed (40 g SID Lys and 13.3 Mcal ME) from day 107 of gestation until parturition. Movement from gestation to farrowing occurred at day 113 (± 2 d) of gestation. Weaning occurred at day 18 to 24 of lactation.
[2]Piglets were cross-fostered within regimen between 24 and 48 h. Weights are adjusted to reflect the addition or subtraction of fostered piglets.
[3]Litter gain = Litter weaning weight – litter weight after cross foster.
[4]Significant regimen within parity differences. Values within the parity category without a common superscript differ ($P < 0.05$).
[5]Count after cross-fostering used as a covariate.
[6]Fallbacks were pigs removed due to weight loss or injury and moved to a nurse sow. This occurred between days 3 and 10 of age and is divided by the litter count after cross-fostering.
[7]Mortality that occurred after cross-fostering until weaning does not include mortality in the first 24 h.
[8]Percentage weaned = litter count at weaning/litter count after cross foster.

lead to reduced milk output. If the sow is not able to mobilize enough body tissue to balance the reduced energy or AA from feed intake, milk production will be reduced leading to reduced litter growth. Cools et al. (2014) demonstrated that fat sows (>22 mm back fat at day 108) had reduced litter weaning weights when fed ad libitum peripartum compared with thin sows (<18 mm) and concluded that additional feed intake from day 108 of gestation through parturition tended to have a positive effect on litter weaning weights as long as the sows were not over conditioned peripartum. In the current study, backfat averaged 21.3 mm when moved to farrowing (day 113) for the gilts that received 3.8 kg/d starting on day 107 of gestation. This would classify approximately 50% of females on that feeding regimen in the fat category of the Cools et al. (2014) study, thus potentially explaining why the additional feed prior to farrowing was not a benefit to weaning weights in contrast to the benefit observed in BiWt.

Litter characteristics

There was no evidence for difference ($P > 0.05$) in total born, born alive, stillborn, and litter size at 24 h, or survival of piglets to 24 h regardless of dietary regimen. Several studies report an increase in the stillborn rate when sows (Goncalves et al., 2016b) or gilts (Mallmann et al., 2019) are supplied with an increased feed allowance from day 90 of gestation to farrowing. Conversely, no difference in stillborn rate has been observed in gilts (Goncalves et al, 2016b) or multiparous sows (Mallmann et al., 2018; Che et al., 2019; Wiegert, 2019). This discrepancy in stillborn data may be due to the variation in sample size or assistance protocol during farrowing, thus making it difficult to conclude an effect on stillborn rate in the literature.

Wean age was similar across all dietary regimens and averaged 20.7 d. There was no evidence for difference in the percentage of pigs recorded as fallbacks, regardless of regimen. Mortality after cross-fostering to weaning was lower ($P < 0.05$) in sows that received 3.8 kg/d lactation diet starting on day 113 compared with control sows, with no evidence for difference in gilts. This resulted in a greater ($P < 0.05$) percentage of pigs weaned from sows that received 3.8 kg/d of lactation diet starting on day 113 compared with the control sows or sows that received lactation diet starting on day 107, again with no change in gilts fed different regimens. Although only numerically different, after cross-fostering, the 3.8 kg/d lactation diet starting on day 113 regimen had 0.5 less pigs per litter than the other two regimens which could have allowed for less competition, leading to fewer mortalities. There are few studies that evaluate preweaning mortality when late gestation feeding treatments were applied, and they typically have small sample sizes per treatment (10 to 30 sows). Regardless, no evidence for differences in preweaning mortality was observed in gilts (Mallmann, et al., 2019) or sows (Che et al., 2019) fed 21 g/d SID Lys from day 90 of gestation, or multiparous sows fed 1.5 to 4.5 kg/d lactation diet on day 104 of gestation (Garrison et al., 2017).

Colostrum composition and yield

Colostrum fat and total solids were decreased ($P < 0.05$) in sows that received the lactation diet starting on day 107 compared with the control sows, with no evidence for difference observed in gilts (Table 5). Of the colostrum components, fat is the easiest to change through nutritional strategies (Farmer and Quesnel, 2009). Typically, the addition of fat in the diet prior to parturition will increase fat content in colostrum (Krogh et al., 2012) or fatty acid profile (Decaluwé et al., 2014). Recently, no evidence for difference was reported in sows fed increased energy on day 90 (Che et al., 2019) or energy and Lys on day 80 of gestation (Yang et al., 2009). However, it has been demonstrated that restricting feed intake prior to parturition (1.0 vs. 3.7 kg/d) increased colostrum fat content (Göransson, 1990), whereas overfeeding in late gestation can harm mammogenesis by depositing excess fat in the mammary tissues (Farmer and Sorensen, 2001). Therefore, the decrease in colostrum fat in the current study could be due to over conditioning of sows with the increased Lys and energy for 3 to 8 d prior to farrowing, resulting in excess fat in the mammary tissue.

Table 5. Increased lysine and energy feeding duration prior to parturition on colostrum quality and yield within parity category

	Gilts				Sows			
Response	Control	Day 113	Day 107	SEM	Control	Day 113	Day 107	SEM
Count, n	46	46	45	—	113	110	112	—
Fat,[2] %	5.4	5.4	5.3	0.21	4.7[a]	4.6[ab]	4.4[b]	0.13
Protein,%	14.8	14.9	15.1	0.27	15.3	14.9	15.1	0.17
Solids,[2] %	24.7	25.3	25.1	0.36	24.6[a]	24.1[ab]	24.0[b]	0.22
Lactose, %	3.2	3.1	3.2	0.05	3.1	3.2	3.2	0.03
IgG,[3] mg/mL	107	125	105	1.6	114	131	126	1.3
Colostrum yield,[4,6] kg	5.35	5.37	5.28	0.23	5.99	6.13	6.02	0.13
Colostrum intake,[5,6] g	445	437	436	17.0	461	480	460	11.0

[1]A total of 467 sows were used from day 106 of gestation until weaning Regimens consisted of: 1) Control: 2.0 kg/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until day 113 of gestation, then 2.7 kg/d lactation feed (28 g SID Lys and 9.4 Mcal ME) until parturition; 2) 2.0 kg/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until day 113 of gestation, then 3.8 kg/d lactation feed (40 g SID Lys and 13.3 Mcal ME) until parturition; or 3) 3.8 kg/d lactation feed (40 g SID Lys and 13.3 Mcal ME) from day 107 of gestation until parturition. Movement from gestation to farrowing occurred at day 113 (± 2 d) of gestation. Weaning occurred at day 18 to 24 of lactation; 50 mL of colostrum was collected within 3 h from the onset of parturition from multiple teats. Samples were sent to a commercial laboratory (Stearns DHIA Lab, Sauk Centre, MN) and analyzed in duplicate for fat, protein, lactose, and total solids (Combi-Foss milk analyzer, Foss Analytics, Denmark). Immunoglobulin G concentration was analyzed in duplicate using the porcine colostrum IgG ELISA Quantitation Kit (Bethyl Laboratories, Montgomery, TX).
[2]Significant regimen within parity differences. Values within the parity category without a common superscript differ ($P < 0.05$).
[3]Main effect of regimen: control vs. day 113 ($P < 0.05$).
[4]Total colostrum intake for the litter.
[5]Average colostrum intake of a piglet calculated as: $-106 + 2.26\ WG + 200\ BWB + 0.111\ D - 1{,}414\ WG/D + 0.0182\ WG/BWB$, where WG is 24 h piglet weight gain in grams, D is the duration of colostrum suckling in minutes, and BWB is body weight at birth.
[6]Pig:teat ratio used as a covariate.

There was no evidence for difference ($P > 0.05$) in colostrum protein or lactose concentrations due to dietary regimens. Previous literature is inconsistent on colostrum composition changes due to increasing energy and Lys by feed amount or ingredient composition prior to farrowing. Increasing gestation feed amount from 1.5 to 4.5 kg/d for 7 d prior to farrowing increased colostrum lactose and decreased protein (Decaluwé et al., 2014). In a late gestation energy and AA study, no change in lactose, protein, or total solids in colostrum occurred (Che et al., 2019). Large changes in colostrum composition occur within the first 24 h after the birth of first pig and also differ between anterior and posterior teats (Hurley, 2015). Therefore, differences in time or method of sample collection may have led to the inconsistent response in the literature.

Immunoglobulin G, which provides passive immunity to the piglet (Rooke and Bland, 2002), was increased ($P < 0.05$) in both gilts and sows that received 3.8 kg/d lactation diet starting on day 113 compared with the control, which was largely driven by the increase in the gilts. Increasing AA in late gestation (Che et al., 2019) or feed allowance (Decaluwé et al., 2014) did not result in increased IgG concentrations. Interestingly, Decaluwé et al. (2014) observed a numerical reduction (153 vs. 249 g) in IgG concentration in fat (<23 mm backfat) compared with thin sows. As previously mentioned, sows in the current study were heavily conditioned in late gestation, and the additional energy resulted in increased backfat gain and may have decreased the IgG concentration in the colostrum of those fed 3.8 kg/d lactation diet starting on day 107.

In the current study, sow colostrum yield and piglet colostrum intake had no evidence for difference ($P > 0.05$) due to dietary regimen applied pre-farrowing. Previous research observed that moderate-conditioned (17 to 22 mm backfat) sows consuming ad libitum feed prior to parturition expressed greater colostrum yield compared with those restricted to 1.5 kg/d which mobilized body reserves prior to farrowing (Decaluwé et al., 2014). Wiegert (2019) observed an increase in colostrum yield when sows were provided 3.0 or 4.5 kg/d lactation diet compared with 1.5 kg/d beginning on day 104 of gestation, but caution must be used in interpretation as only 10 sows were used per treatment in their study. Conversely, Mallmann et al. (2019) observed a linear decrease in colostrum yield as gestation feed amount increased from 1.8 to 3.3 kg/d starting at day 90 of gestation. However, this is likely due to the difference in backfat change from day 90 to parturition, where fat sows (>22 mm of backfat) are known to have decreased colostrum yield (Decaluwé et al., 2014). We speculate that the females in the current study fed the control diet were not restricted the nutrients needed to synthesize colostrum, as backfat prior to farrowing was not mobilized to support colostrogenesis (Farmer and Quesnel, 2009). Therefore, the reason colostrum yield did not change when sows were supplied with additional feed prior to farrowing could be due to requirements for colostrogenesis being met and additional Lys and energy not being partitioned toward colostrum, or that the range in sow body condition was not changed at a great enough magnitude (0.2 to 0.9 mm gain in backfat) 7 d prior to parturition to allow for an observed change in colostrum yield due to consuming increased energy and Lys.

Reproductive performance

There was no evidence for difference ($P > 0.05$) in wean-to-estrus interval, percentage of females in estrus by day 7, or farrowing rate regardless of dietary regimen that had been fed in the previous transition period (Table 6). In addition, total born or percentage born alive, stillborn, or mummified in the subsequent litter were similar ($P > 0.05$) across dietary regimens that had been fed in the previous transition period. Several other studies have also noted no evidence for differences in wean-to-estrus interval or females in estrus by day 7, total born, or born alive due to late gestation feeding levels in the previous parity (Goncalves et al., 2016b; Garrison et al., 2017; Mallmann et al., 2018, 2019). This suggests that the changes in BW and backfat loss during lactation in the current study were not severe enough to affect follicular development (Clowes et al., 2003) or embryonic survival (Vinsky et al., 2006), thus leading to no evidence for differences in subsequent reproductive performance.

In summary, feeding increased Lys and energy starting on day 107 or 113 of gestation increased weight gain and backfat depth of gilts and sows peripartum compared with the control regimen. There was no evidence that the additional weight and backfat gain pre-farrowing resulted in weight or backfat loss during the lactation period. Average piglet BW for total pigs born and pigs born alive was increased in gilts fed increased Lys and energy starting on day 107 or 113 of gestation. However, litter gain to weaning was reduced in gilts fed increased Lys and energy starting at day 107 of gestation compared with

Table 6. Increased lysine and energy feeding duration prior to parturition on subsequent reproductive performance within parity category[1]

	Gilts				Sows			
Response	Control	Day 113	Day 107	SEM	Control	Day 113	Day 107	SEM
Sows, *n*	42	43	41	—	99	98	100	—
Wean to estrus interval, d	5.0	5.0	5.3	0.59	4.9	4.9	4.9	0.35
In estrus by day 7, %	86.2	88.4	90.0	5.81	94.8	93.8	96.0	2.45
Farrowing rate, %	92.1	80.0	87.5	6.34	90.8	90.8	91.3	3.01
Litters, *n*	33	33	35	—	86	89	91	—
Subsequent litter								
Total born, *n*	13.5	13.6	14.5	0.64	14.9	15.8	15.7	0.41
Born alive, %	96.2	93.3	95.0	1.27	91.6	92.8	93.5	0.86
Stillborn, %	3.2	4.8	2.9	1.06	6.6	6.2	4.9	0.75
Mummified, %	0.6	1.9	2.2	0.66	1.8	0.9	1.6	0.38

[1]A total of 423 sows were recorded for a wean to estrus interval, and 363 sows from that group had subsequent farrowing data. Regimens consisted of: 1) Control: 2.0 kg/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until day 113 of gestation, then 2.7 kg/d lactation feed (28 g SID Lys and 9.4 Mcal ME) until parturition; 2) 2.0 kg/d gestation feed (12.5 g SID Lys and 6.5 Mcal ME) until day 113 of gestation, then 3.8 kg/d lactation feed (40 g SID Lys and 13.3 Mcal ME) until parturition; or 3) 3.8 kg/d lactation feed (40 g SID Lys and 13.3 Mcal ME) from day 107 of gestation until parturition. Weaning occurred at day 18 to 24 of lactation.

the control gilts resulting in no change in weaning weights. There was reduced piglet mortality from sows fed increased Lys and energy starting on day 113 of gestation compared with sows fed the control regimen. Colostrum yield and intake and subsequent reproductive performance were unaffected by dietary regimens. It can be concluded that with this level of herd productivity and above-average sow body condition, feeding increased Lys and energy to gilts at the time of movement to farrowing rooms (approximately day 113 of gestation) may be adequate to meet the additional Lys and energy requirements for fetal growth, as measured by increased piglet BiWt in gilts. There was little evidence that feeding increased Lys and energy prior to farrowing impacted sow performance.

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Conflict of interest statement

The authors declare no real or perceived conflict of interest.

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