Feeding sows during the transition period—is a gestation diet, a simple transition diet, or a lactation diet the best choice?[1]

Trine Friis Pedersen,* Sophie van Vliet,* Thomas Sønderby Bruun,† and Peter Kappel Theil*[2]

*Department of Animal Science, Animal Science, Faculty of Science and Technology, Aarhus University, DK-8830 Tjele, Denmark; and †SEGES Danish Pig Research Centre, DK-1609 Copenhagen, Denmark

ABSTRACT: Three experiments were carried out to study whether a gestation diet, a simple transition diet, or a lactation diet is the best choice in late gestation and when sows preferably should be transferred to a high crude protein (**CP**) lactation diet. In experiment 1, 35 sows were fed either a gestation diet (12.1% CP), a lactation diet (15.9% CP), or a 50/50 mix (simple transition diet; 14.0% CP) from 6 d before parturition until parturition, to study the impact on farrowing and colostrum performance. In experiment 2, 90 sows were studied from 6 d before parturition until weaning at day 24 and they were fed one of five strategies: a gestation diet until day 3 or day 10 of lactation (strategy 1 and 2) and then lactation diet; a simple transition diet until day 3 or day 10 (strategy 3 and 4) and then lactation diet; or a lactation diet throughout the study (strategy 5). In experiment 3, 124 sows were fed strategy 1 or 5. Sows were weighed and back fat (**BF**) scanned when entering the farrowing unit and at day 2, 10, 17, and 24. Piglets were weighed at birth and after 24 h, and colostrum production was studied (experiment 1). Litter weight at day 2, 10, 17, and 24 was recorded, milk and blood samples were collected weekly and sow fat and protein mobilization, and balances of energy, N, and Lys were calculated from day 3 to 10 of lactation (experiment 2). Total- and live born piglets, and frequencies of stillbirth and piglet diarrhea were recorded (experiment 3). Feeding sows a gestation diet, a simple transition diet, or a lactation diet showed no evidence of effects on colostrum production or farrowing process (experiments 1 and 3) or lactation performance (experiments 2 and 3). Compared to previous studies, sows had a poor milk yield. Plasma urea was elevated ($P < 0.001$) indicating CP oversupply prior to parturition in sows fed the lactation diet as compared with the two other diets. According to calculated balances, all dietary strategies supplied insufficient amounts of N and Lys from day 3 to 10, indicating that the best choice is to feed sows with a high CP lactation diet from parturition and onwards. Primiparous sows had a higher plasma insulin concentration ($P < 0.01$), lower colostrum yield ($P < 0.01$), and higher frequency of piglet diarrhea ($P < 0.001$) than multiparous sows. In conclusion, in our conditions (high CP in gestation diet; poor milk yield; restricted feeding in early lactation), sow performance was not compromised by the dietary strategies, but results indicate that primiparous and multiparous sows should be fed differently.

Key words: colostrum performance, feed utilization, lactation performance, nutrient balances, sow nutrition, transition feeding

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[2]Corresponding author: peter.theil@anis.au.dk

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INTRODUCTION

Sow productivity has improved considerably during the years and modern sows today give birth to on average 16.9 live born piglets per farrowing and wean 33.3 piglets per year (Hansen, 2018). The rapid increase in productivity has led to a higher demand for nutrients (Strathe et al., 2017), and the Danish recommendations of dietary Lys and CP for lactating sows has increased by 28% and 14%, respectively (Tybirk et al., 2012; Tybirk et al., 2015). The Danish recommendations are based on studies beginning day 2 of lactation and it is not known at present, whether the recommendations are suitable for sows in late gestation. As a consequence, sows are likely oversupplied considerably with CP when entering the farrowing unit. This, in turn, may compromise the farrowing process, colostrum production, and milk production in early lactation when milk yield and hence CP requirement is fairly low. A lactation diet is quite low in dietary fiber to avoid reduced average daily feed intake (**ADFI**) at peak lactation, but this is unfortunate because low fiber intake increases stillbirth rate (Feyera et al., 2017) and therefore late gestating sows may benefit from being fed a simple transition diet with intermediate levels of CP and fiber as compared with gestation and lactation diets. Physiological changes occur rapidly during transition from late gestation to early lactation (Feyera and Theil, 2017; Krogh, 2017) and feeding during transition may potentially also have a carryover effect on sow performance during lactation.

The hypothesis was that sows fed a simple transition diet performed better during farrowing, colostrum period, and subsequent lactation as compared with sows fed either a gestation diet or a lactation diet during the transition period. The objectives were 1) to evaluate whether a gestation, a simple transition, or a lactation diet is the best choice during transition in a commercial setting, and 2) to study when sows should be transferred to a high CP lactation diet.

MATERIALS AND METHODS

The experiments were carried out in accordance with the Danish laws and regulations for the humane care and use of animals in research (Law number 382, Act number 726 and 1081 of the Danish Ministry of Justice) and the experimental protocols were approved by The Danish Animal Experimentation Inspectorate.

Animals and Housing

Three parallel experiments were carried out in the period from November 2016 to May 2017, in a commercial Danish sow herd. In total, 249 cross-bred (Danish Landrace × Danish Yorkshire; DanBred, Herlev, Denmark) sows, from first to fourth parity were included in the experiments. Sows and their litters were individually housed in farrowing crates (2.38 × 2.38 m) enabling sows to be fixed around farrowing and loosed housed from day 10 after parturition and until weaning. The flooring consisted of plastic and concrete slatted floor. The temperature was maintained at 20 °C during the experimental period. Piglets had access to a covered area (1.10 × 0.93 m) with a robber mattress and a heating device. The heater (Aniheater, Holsted, Denmark) warmed the covered area from parturition until day 10 in lactation. Rapeseed straw meal was provided as bedding for the piglets in the covered area and sows had free access to straw throughout lactation.

Experiment 1. Thirty-five sows were moved to the farrowing unit and included in the study from 6 d before expected parturition up until day 2 after parturition to evaluate the dietary effects on the farrowing process and colostrum production. Sows were included in the study in two blocks of 19 and 16.

Experiment 2. Ninety sows were included in the study from 6 d before expected parturition up until weaning 24 d after parturition, to evaluate the impact of nutrition in the transition period on sow and piglet performance during lactation. Sows were included in the experiment in groups of 5 to 7, in 15 consecutive weeks (blocks). Within 48 h after parturition, litters were standardized to 14 piglets (average piglet weight was 1.33 kg).

Experiment 3. In a production trial, 124 sows were studied from 6 d before expected parturition up until weaning 24 d after parturition, to evaluate the impact of nutrition in the transition period on sow and piglet performance during lactation. Sows were included in the experiment in groups of 6 in 21 consecutive weeks (blocks). Within 48 h after parturition, litters were standardized to 14 piglets (average piglet weight was 1.33 kg).

Dietary Treatments and Feeding

Three dietary treatments were formulated with three levels of CP of 12.1%, 14.0%, and 15.9% on as-fed basis (Table 1). The low CP diet was formulated to meet the nutrient requirements for gestating sows (Tybirk et al., 2015), including a safety margin. The high CP diet was formulated to meet the nutrient requirements for lactating sows (Tybirk et al., 2015). The intermediary CP diet (i.e., the simple transition

Table 1. Ingredient composition and analyzed chemical composition of gestation and lactation diet in experiments 1, 2, and 3

Item	Diet		
	Gestation	Transition[1]	Lactation
Ingredient composition, %			
Barley	35.0	31.1	27.2
Wheat	16.3	28.2	40.0
Oat	10.0	7.50	5.00
Rye	25.0	15.0	5.00
Soybean meal	5.20	10.8	16.4
Faba beans	5.00	2.50	-
Soy oil	0.50	1.35	2.20
Limestone	1.52	1.53	1.55
Monocalcium phosphate	0.60	0.91	1.22
Sodium chloride	0.50	0.51	0.52
Vitamin and mineral mix A[2]	0.24	0.12	-
Vitamin and mineral mix B[3]	-	0.19	0.37
L-Lys	0.11	0.18	0.26
DL-Met	0.01	0.04	0.07
L-Thr	0.02	0.06	0.09
L-Val		0.01	0.02
Planned chemical composition[4,5]			
ME, MJ/kg	12.5	12.8	13.1
CP	12.1 (9.8)[6]	14.0 (11.7)	15.9 (13.5)
Fat	2.9	3.7	4.5
Starch	46.2	44.1	41.9
Lignin	4.4	4.0	3.6
Ash	4.7	5.3	5.8
Cys	0.25 (0.20)	0.27 (0.22)	0.29 (0.24)
His	0.28 (0.23)	0.33 (0.28)	0.38 (0.33)
Ile	0.45 (0.37)	0.53 (0.45)	0.62 (0.52)
Leu	0.83 (0.68)	0.98 (0.82)	1.12 (0.95)
Lys	0.61 (0.51)	0.78 (0.67)	0.94 (0.82)
Met	0.19 (0.16)	0.24 (0.21)	0.29 (0.26)
Phe	0.57 (0.48)	0.66 (0.56)	0.75 (0.65)
Thr	0.43 (0.33)	0.53 (0.44)	0.63 (0.54)
Trp	0.15 (0.12)	0.18 (0.15)	0.21 (0.18)
Val	0.58 (0.45)	0.66 (0.54)	0.75 (0.63)
Analyzed chemical composition[5]			
GE, MJ/kg	16.6	16.8	17.0
DM	85.5	85.9	86.3
CP	13.1	14.9	16.7
Fat	2.6	3.8	5.0
Starch	51.4	46.7	41.9
Dietary fiber	16.4	15.5	14.6
Lignin	2.8	2.7	2.6
Ash	4.1	4.5	4.9
Ca	0.65	0.70	0.75
P	0.44	0.51	0.58
Cys	0.24	0.26	0.27
Lys	0.64	0.80	0.96
Met	0.21	0.25	0.29
Thr	0.47	0.56	0.64

[1]Transition diet is calculated as 50% gestation diet and 50% lactation diet.

[2]Supplied per kg of diet: Retinol, 8063 IU; cholecalciferol, 806 IU; α-tocopherol, 94.1 IU; DL-α-tocopherol, 85.7 mg; menadione, 4.03 mg; thiamin, 2.02 mg; cyanocobalamin, 0.02 mg; riboflavin, 5.04 mg; pyridoxine, 3.02 mg; biotin, 0.40 mg; D-pantothenic acid, 15.1 mg; folic acid, 1.51 mg; niacin, 20.2 mg; Cu, 15.1 mg as $CuSO_4$; Zn, 101 mg as ZnO; Fe, 80.6 mg as $FeSO_4$; I, 0.20 mg as CaI; Mn, 40.3 mg as MnO; Se, 0.35 mg as Na_2SeO_3.

[3]Supplied per kg of diet: Retinol, 8362 IU; cholecalciferol, 836 IU; α-tocopherol, 207 IU; DL-α-tocopherol, 188 mg; menadione, 4.18 mg; thiamin, 2.09 mg; cyanocobalamin, 0.02 mg; riboflavin, 5.23 mg; pyridoxine, 3.14 mg; biotin, 0.42 mg; D-pantothenic acid, 15.7 mg; folic acid, 1.57 mg; niacin, 20.9 mg; Cu, 15.7 mg as $CuSO_4$; Zn, 99.3 mg as ZnO; Fe, 83.6 mg as $FeSO_4$; I, 0.21 mg as CaI; Mn, 41.8 mg MnO; Se, 0.37 mg as Na_2SeO_3.

[4]Planned chemical values are derived from EvaPig, using nutrient content from Danish feedstuffs.

[5]Items are presented as % (as-fed) unless otherwise is noted.

[6]Values in parentheses are standardized ileal digestible (**SID**) values (Pedersen and Boisen, 2002).

diet) was a 50/50 mixture of the gestation diet and the lactation diet. In experiment 1, sows were allotted to one of the three diets stratified for parity and fed from 6 d before parturition until day 2 of colostrum period. In experiment 2, sows were allotted to one of five dietary strategies stratified for parity (Figure 1). Sows fed strategy 1 and 2 received the gestating diet from 6 d before parturition up until day 3 or 10, respectively, where after they received lactation diet until weaning at day 24. Sows fed strategy 3 and 4 received the simple transition diet from 6 d before parturition up until day 3 or 10, respectively, where after they received lactation diet until weaning. Sows fed strategy 5 received the lactation diet throughout the experiment, that is, from 6 d before parturition up until weaning. In experiment 3, sows were allotted to strategy 1 and 5 stratified for parity.

The three dietary treatments were mixed two to three times per week and distributed automatically by an Agrisys AirFeed feeding system (Agrisys, Herning, Denmark). At each meal, the feeding system weighed the feed for each individual sow, based on the predetermined feeding curve. All sows received the same amount of feed on a net energy (**NE**) basis (around 3.0 kg from 6 d before parturition until 2 d after parturition). From day 2 in lactation, feed supply increased gradually to reach 8.0 kg at day 16 of lactation. From day 17 to weaning, the feed supply increased to 9.0 kg at weaning. Sows that were not able to ingest the planned feed allowance had reduced their supply to 50% of the planned supply at the following meal and hereafter 75% and 100% of planned feed supply in the following two meals. After day 10 in lactation, the feed supply was adjusted according to number of piglets in the litter, where feed intake was reduced by 5% for each

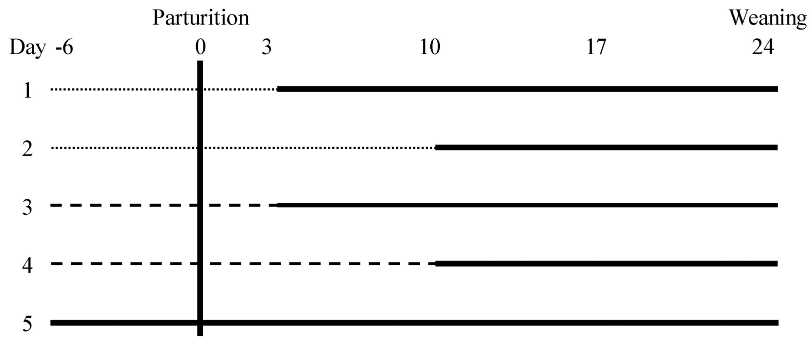

Figure 1. Sows in experiment 2 were fed one of five dietary strategies (n = 90), sows fed strategy 1 and 2 were fed the gestating diet (·····) from 6 d before parturition and until day 3 or 10, respectively, where after they changed to lactation diet until weaning. Sows fed strategy 3 and 4 were fed the simple transition diet (---) from 6 d before parturition and until day 3 and 10, respectively, where after they changed to the lactation diet until weaning. Sows fed strategy 5 were fed the lactation diet from 6 d before parturition and until weaning (—).

piglet below 14. Sows were fed twice daily from they entered the farrowing unit until day 9 in lactation, at 0800 h and again at 1400 h. From day 10 until weaning, sows were fed three times daily at 0600 h, 1400 h, and 2000 h. Feed was mixed with water in the troughs when distributed to the sows. In addition, sows had free access to water throughout the lactation period.

Experimental Procedure

Experiment 1. Sows were weighed and back fat (**BF**) scanned 2 d after parturition. Back fat was measured using a Lean-Meater (RENCO, MN, USA), at the last rib on the right side, 65 mm from the backbone (conventionally known as P2 measurement). Piglets were weighed individually at birth (after drying and shortening of the umbilical cord to 10 cm) and 24 h after birth of the first piglet in the litter. Colostrum samples were collected 0 and 24 h after onset of parturition. The 24 h colostrum sample was collected after separation of piglets from the sow for 10 min followed by i.v. injection of 0.3 mL oxytocin (Intervet Danmark A/S, Ballerup, Denmark) in the ear vein to induce milk let down. A total of 60 to 70 mL of colostrum was sampled, and the colostrum was filtered (for debris) followed by storing at −20 °C until analysis.

Experiment 2. Sows were weighed and BF scanned when entering the farrowing unit (6 d before parturition) and at day 2, 10, and 17 after parturition and at weaning (day 24). Litters were weighed and standardized to 14 piglets within 48 h after parturition. The piglets were weighed again at day 10, 17, and 24 after parturition. Milk samples were collected 3, 10, and 17 d after parturition. Piglets were separated from the sow for 10 min and the sows were fixed and injected 0.3 mL oxytocin i.v. in the ear vein to induce milk let down. A total of 60 to 70 mL of milk was sampled at each collection. After each milk sampling, the milk was filtered (for debris) followed by storing at −20 °C until analysis.

Blood samples were drawn 3 to 4 h after morning feeding 3 d before parturition and at day 3, 10, and 17 of lactation. Blood samples were collected by jugular vein puncture, collected in 9 mL heparinized vacutainers (Greiner BioOne GmbH, Kremsmünster, Austria). The heparinized vacutainers were placed on ice immediately after blood collection. All blood samples were centrifuged at 1,558 × g at 4 °C for 10 min followed by plasma harvest and stored at −20 °C until analysis. To evaluate body composition at day 3 and 10 after parturition, sows were enriched with deuterated water (**D_2O**), supplying 0.0425 g per kg BW of a 40% D_2O solution. For measuring D_2O background, a reference blood sample was drawn followed by i.m. injection of D_2O. Three to 4 h after enrichment, a blood sample was drawn to determine the total D_2O space as described by Theil et al. (2002). Blood for D_2O analysis was collected in a 4 mL silica vacutainer (BD, Plymouth, UK) and samples were allowed to clot before they were centrifuged at 1,558 × g at 4 °C for 10 min followed by serum harvest and storing at −20 °C until analysis.

Experiment 3. Litters were standardized to 14 piglets within 48 h after parturition. Within the first week of lactation (at one specific week day for all litter irrespective of farrowing day), absence (score = 0) or presence (score = 1) of diarrhea was recorded for all individual piglets.

Chemical Analysis

The diets were subsampled every second week, pooled at the end of both experiments and analyzed in duplicate for gross energy (**GE**), dry matter (**DM**), ash, nitrogen (**N**), crude fat, dietary fiber, starch, lignin, AA, Ca, and P. Analysis for DM, ash, N, crude fat, Ca, P, and AA were conducted by Eurofins Steins Laboratorium A/S (Vejen, Denmark) according to the Official Journal of the European Union (EU; 152/2009). Prior to chemical analysis of GE, starch, dietary fiber and lignin, the diets were freeze dried and subsequently ground to 0.5 mm using an ultra-centrifugal mill (Model ZM200; RETSCH, Haan, Germany). Gross energy in diets was determined using an adiabatic bomb calorimeter (Model 6300; Parr Instrument, Moline, IL), where benzoic acid was used as a standard for calibration. The content of starch was analyzed by enzymatic colorimetry according to the method described by Bach Knudsen (1997). Total dietary fiber including lignin was analyzed by enzymatic, chemical, and gravimetric determination of soluble and insoluble fibers according to Bach Knudsen (1997) with the modification that the polysaccharides were hydrolyzed with 2 M H_2SO_4 for 2 h.

Sow colostrum and milk samples were analyzed in triplicate for composition of DM, fat, protein, casein, and lactose contents with infrared spectroscopy using a Milkoscan 4000 (Foss MilkoScan, Hillerød, Denmark).

Plasma insulin was analyzed by enzyme immunoassay using a Mercodia Porcine Insulin ELISA kit (Mercodia AB, Uppsala, Sweden). The plasma concentration of glucose, lactate, TAG and urea was analyzed according to standard procedures (Siemens Diagnostics Clinical Methods for ADVIA 1650) using an auto analyzer (ADVIA 1650 Chemistry System, Siemens Medical Solution, Tarrytown, NY). Plasma content of nonesterified fatty acid (**NEFA**) was determined using the Wako, NEFA C ACS-ACOD assay method (Wako Chemicals GmbH, Neuss, Germany). Serum samples were analyzed after ultrafiltration for D_2O according to the method described by Theil et al. (2002).

Calculations

The planned dietary content of SID CP and AA were estimated based on Pedersen and Boisen (2002; Table 1). Sow colostrum yield was calculated by summing up each piglet's colostrum intake (**CI**; g) for 24 h. Piglet colostrum intake was estimated from piglet weight gain from birth to 24 h after birth of the first piglet (**WG**; g), birth weight of piglets (**BWB**; kg), and the duration of colostrum suckling (**D**; min) in the following equation (Theil et al., 2014):

$$\mathrm{CI} = -106 + 2.26 \times \mathrm{WG} + 200 \times \mathrm{BWB} + 0.111 \times \mathrm{D} - 1{,}414 \times \mathrm{WG/D} + 0.0182 \times \mathrm{WG/BWB} \quad [1]$$

The energy content in milk was estimated as the energy contribution from total milk protein, fat and lactose, based on energy values of 23.9, 39.8, and 16.5 kJ/g of protein, fat and lactose, respectively (Weast, 1977). For milk energy, the fat concentration was multiplied by 0.90 and protein by 1.10, because Milkoscan overestimates the milk fat content by 10% and underestimates the milk protein by 10%, compared to analysis by the classical methods for milk fat and protein (Krogh, 2017). Sow body pools of fat and protein were estimated using Rozeboom et al. (1994) prediction equations for Landrace × Yorkshire gilts. To derive sow body pools of protein and fat, sow BW (kg), D_2O space (kg), and BF (mm) were used as inputs for each sow in the following equations:

$$\text{Body protein [kg]} = 1.3 + 0.103 \times \mathrm{BW} + 0.092 \times \mathrm{D_2O\ space} - 0.108 \times \mathrm{BF} \quad [2]$$

$$\text{Body fat [kg]} = 7.7 + 0.649 \times \mathrm{BW} - 0.610 \times \mathrm{D_2O\ space} + 0.299 \times \mathrm{BF} \quad [3]$$

The mobilization of fat and protein from day 3 to day 10 of lactation was estimated by subtracting body pools at day 3 from those derived at day 10.

The metabolism of energy, N, and Lys was calculated from day 3 to 10 of lactation. The metabolizable energy (**ME**) intake was calculated as ADFI from day 3 to 10 of lactation multiplied by the estimated ME content in feed (calculated in EvaPig using table values for Danish feed ingredients). The daily maintenance requirement for energy was calculated using sow BW and energy required per kg metabolic BW (0.482 MJ/kg$^{0.75}$; Theil et al., 2004). The energy output in milk was calculated as the average energy content in milk from day 3 and 10 multiplied by sow milk yield estimated from day 3 and 10. Sow milk yield was estimated as 4.18 g milk/g gain multiplied by litter gain from day 3 to 10 (adapted from Theil et al., 2002). Heat energy associated with milk production was calculated assuming an efficiency of energy for milk production of 0.78 according to Theil et al. (2004). The daily energy retention (**RE**) from day 3 to 10 in lactation was calculated as ME intake minus ME requirement. The ME requirement is the sum of energy required for maintenance (**ME_m**), energy secreted in milk (**E_{milk}**), and heat associated with milk production (**HE_{milk}**). Thus, RE and dietary NE corrected for energy mobilization (**NEc**) were estimated according to Pedersen et al. (2019b) as follows:

$$\text{ME requirement [MJ/d]} = \text{ME}_{\text{m}}\,[\text{MJ/d}] + \text{E}_{\text{milk}}\,[\text{MJ/d}] + \text{HE}_{\text{milk}}\,[\text{MJ/d}] \quad [4]$$

$$\text{RE [MJ/d]} = \text{ME}_{\text{intake}}\,[\text{MJ/d}] - \text{ME requirement}\,[\text{MJ/d}] \quad [5]$$

$$\text{NEc [MJ/kg]} = (\text{ME}_{\text{M}} + \text{E}_{\text{milk}} + \text{RE})\,[\text{MJ/d}]\,/\,\text{ADFI [kg/d]} \quad [6]$$

The SID N intake (**SID N$_{\text{intake}}$**) was calculated as ADFI from day 3 to 10 in lactation multiplied by the estimated analyzed SID CP content in feed divided by 6.25. The daily urinary N loss (N$_{\text{urine}}$) was calculated from the following regression equation according to values adapted from Pedersen et al. (2019a):

$$\text{Urinary N loss [\% of intake]} = 2.1691 \times \text{Dietary SID CP [\%]} - 4.6924 \quad [7]$$

The N output in milk (**N$_{\text{milk}}$**) was calculated as the average N concentration in milk (milk protein divided by 6.38 and corrected by 1.10 as described above) from day 3 and 10 in lactation multiplied by the mean milk production from day 3 to 10. The daily retention of N (**RN**) from day 3 to 10 in lactation was calculated as the SID N intake minus N excreted in urine (**N$_{\text{urine}}$**) and N$_{\text{milk}}$, where a negative value of retention indicate mobilization:

$$\text{RN [g/d]} = \text{SID N}_{\text{intake}}\,[\text{g/d}] - (\text{N}_{\text{urine}}\,[\text{g/d}] + \text{N}_{\text{milk}}\,[\text{g/d}]) \quad [8]$$

The corrected utilization of dietary SID N for milk production (**UNMc**) was calculated by correcting for N being mobilized from sow muscle mass (**Nmob**). Where Nmob is calculated as SID N$_{\text{intake}}$ minus N milk utilization (**NMU**) and N$_{\text{milk}}$. N milk utilization is calculated by assuming an efficiency of N for milk production of 0.78 (Strathe, 2017):

$$\text{NMU [g/d]} = (\text{N}_{\text{milk}}\,[\text{g/d}]\,/\,0.78) - \text{N}_{\text{milk}}\,[\text{g/d}] \quad [9]$$

$$\text{Nmob [g/d]} = \text{SID N}_{\text{intake}}\,[\text{g/d}] - (\text{NMU [g/d]} + \text{N}_{\text{milk}}\,[\text{g/d}]) \quad [10]$$

$$\text{UNMc [\% of intake]} = (\text{N}_{\text{milk}}\,[\text{g/d}] + \text{Nmob [g/d]}) \times 100\,/\,\text{SID N}_{\text{intake}}\,[\text{g/d}] \quad [11]$$

The SID Lys intake (**SID L$_{\text{intake}}$**) was calculated as average feed intake from d 3 to 10 of lactation multiplied by the estimated analyzed dietary SID Lys content. The daily maintenance requirement for Lys (**MRL**) was calculated as 46.26 mg/kg$^{0.75}$ (NRC, 2012). The Lys output in milk (**L$_{\text{milk}}$**) was calculated as 7.01 % of the protein content in milk (NRC, 2012) from day 3 and 10 multiplied by the milk yield from day 3 to 10. The daily retention of Lys (**LN**) from day 3 to 10 of lactation was calculated as the sum of SID L$_{\text{intake}}$ minus MRL and Lmilk:

$$\text{LN [g/d]} = \text{SID L}_{\text{intake}}\,[\text{g/d}] - (\text{MRL [g/d]} + \text{L}_{\text{milk}}\,[\text{g/d}]) \quad [12]$$

The corrected utilization of dietary SID Lys for milk production (**ULMc**) was calculated by correcting for Lys being mobilized from sow muscle mass (**Lmob**). Where Lmob is calculated as SID L$_{\text{intake}}$ minus Lys milk utilization (**LMU**) and N$_{\text{milk}}$. The utilization of Lys for milk production was calculated by assuming an efficiency of 0.91 (Strathe, 2017):

$$\text{LMU [g/d]} = (\text{L}_{\text{milk}}\,[\text{g/d}]\,/\,0.91) - \text{L}_{\text{milk}}\,[\text{g/d}] \quad [13]$$

$$\text{Lmob [g/d]} = \text{SID N}_{\text{intake}}\,[\text{g/d}] - (\text{NMU [g/d]} + \text{N}_{\text{milk}}\,[\text{g/d}]) \quad [14]$$

$$\text{ULMc [\% of intake]} = (\text{L}_{\text{milk}}\,[\text{g/d}] + \text{Lmob [g/d]}) \times 100\,/\,\text{SID L}_{\text{intake}}\,[\text{g/d}] \quad [15]$$

Statistical Analyses

Data from experiments 1, 2, and 3 were analyzed as separate incomplete block designs using the MIXED procedure of SAS (version 9.3, SAS Inst. Inc., Cary, NC). The effect of feeding sows a gestation diet, a simple transition diet, or a lactation diet, from 6 d before parturition on farrowing traits (sow CY, colostrum composition, farrowing length, total born piglets, live born piglets, and mean piglet birth weight) and the effect of feeding sows different strategies during the transition period were analyzed using the following model:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \delta_k + \varepsilon_{ijk},$$

Where Y_{ijk} is the observed trait, μ is the overall mean of the observations, α_i is the main effect of the dietary treatments/strategies (i = 3 dietary treatments in experiment 1, i = 5 dietary strategies in experiment 2, and i = 2 strategies in experiment 3), β_j is the main effect of parity (*j* = primiparous or multiparous), δ_k is the random effect of block (in experiment 1, *k* = 1 or

2, in experiment 2, $k = 1, 2,\ldots, 15$, and in experiment 3, $k = 1, 2,\ldots, 21$), and ε_{ijk} is the residual random component. The main effects of dietary treatments/strategies on sow milk composition and plasma metabolites were analyzed in a similar model, where repeated measurements within sow were taken into account. Mean values are presented as least squares means ± standard error of the mean. No interactions between treatment and parity or treatment and day (repeated measurement model) were observed for any variables and were therefore omitted in the final model. Mean values of farrowing length, piglet birth interval, and plasma NEFA were logarithmic transformed to stabilize the residual variance. Piglet stillbirth rate and the frequency of piglet diarrhea were analyzed as odds ratios using the GLIMMIX procedure of SAS (version 9.3, SAS Inst. Inc., Cary, NC) by taking repeated measurements within blocks into account and results are given as least squared means and the associated 95% CI. Multiple mean comparisons were accounted for by adjusting the *P* values using a Tukey test. Correlations between milk fat (day 3, 10, and 17) and sow BF at day 2 and milk yield day 3 to 10 were analyzed as Pearson correlation coefficients using the CORR procedure in SAS (version 9.3, SAS Inst. Inc.). Statistical significance was accepted when $P < 0.05$ and tendencies were accepted at $P \leq 0.10$.

RESULTS

The analyzed nutrient composition of the gestation diet and lactation diet is listed in Table 1 along with the calculated content of the transition diet. The analyzed CP concentration of the diets (13.1% for gestating diet and 16.7% for lactation diet) were higher than the planned values of 12.1% CP and 15.9% CP for the gestation and lactation diet, respectively. As expected, the concentration of CP, AA, and fat, was lower for the gestation diet, than the lactation diet, whereas the gestation diet contained more starch and dietary fiber.

Experiment 1. No evidence of effects on feeding sows a gestation, a transition, or a lactation diet from 6 d before parturition until the end of colostrum period was found for the number of total born piglets, piglet birth weight, farrowing length, birth interval, colostrum yield, colostrum intake, or colostrum composition (Table 2). Primiparous sows produced less colostrum (5.2 vs. 7.1 kg) compared to multiparous sows ($P < 0.01$). Mean birth weight of piglets from primiparous sows was lower compared to piglets from multiparous sows (1.00 vs. 1.17 kg; $P = 0.02$).

Experiment 2. Two sows were excluded from the experiment at day 3 in lactation due to agalactia. No evidence of effects on feeding sows a gestation, a transition, or a lactation diet from 6 d before parturition was found for the plasma concentrations of insulin, glucose, lactate, NEFA, or TAG at day 112 of gestation (Table 3). Plasma urea at day 3 in lactation was highest for sows fed the lactation diet and lowest for sows fed the gestation diet ($P < 0.001$).

Sow ADFI, BW loss, BF loss, protein and fat mobilization, and sow milk yield from day 3 to 10 during lactation did not differ among dietary strategies (Table 4). Litter gain was lowest for sows fed the transition diet until day 10, highest for sows fed the lactation diet throughout the experimental period, and intermediate for sows fed the three remaining strategies ($P = 0.04$). Piglet average daily gain (**ADG**) (day 2 to 24) was lowest for sows fed the transition diet until day 10, highest for sows fed the transition diet until day 3, and intermediate for sows fed the three remaining strategies ($P = 0.04$).

The ME intake from day 3 to 10 of lactation was highest for sows fed the transition diet until day 3, lowest for sows fed the gestation diet until day 10, and intermediate for sows fed the remaining three strategies (Table 5; $P = 0.04$). The GE intake, maintenance requirement, energy output in milk, and energy retention did not differ among strategies. The net energy corrected for mobilization (**NEc**) content in feed tended to be lower for sows fed the gestation diet until day 10 in lactation (9.7 MJ/kg; $P = 0.07$) as compared with the four other strategies (10.3 to 10.5 MJ/kg). The total and standardized ileal digestible (**SID**) intake of N and Lys and urine N output was lowest for sows fed the gestation diet until day 10, intermediate for sows fed the transition diet until day 10, and highest for sows fed the remaining strategies ($P < 0.001$). The N and Lys output in milk did not differ among strategies. The retention of N and Lys was negative but did not differ among strategies. Milk N utilization corrected for mobilization was lowest for sows fed the gestation diet until day 10, intermediate for sows fed the transition diet until day 10, and highest for sows fed the remaining three strategies ($P = 0.02$). Milk Lys utilization corrected for mobilization was lower for sows fed the gestation diet until day 10 than for the remaining four strategies ($P < 0.001$).

The composition of DM, fat, protein, casein, lactose, and energy in milk did not differ among strategies (Table 6). Milk DM, fat, protein, casein, and energy were higher ($P < 0.001$) at day 3 in lactation, than at day 10 and 17. Milk lactose was lowest at day 3 in lactation and highest at day 10 and 17

Table 2. Farrowing length, piglet birth weight, colostrum yield, intake and composition of sows fed a gestation diet, a transition diet, or a lactation diet from 6 d before parturition (experiment 1)

	Treatment				Parity			*P*-value	
Item	Gestation	Transition	Lactation	SEM	Primi	Multi	SEM	Trt[1]	Parity
No. of sows	14	11	10		6	29			
Mean parity	2.8	2.5	2.8		1	3.1			
Sow weight day 2, kg	244[a]	222[b]	241[ab]	5.99	195	245	8.14	0.01	<0.001
Back fat day 2, mm	14.3	13.0	13.4	0.88	13.2	13.7	1.20	0.49	0.72
Feed intake, kg	3.07	2.95	3.03	0.05	3.03	3.02	0.06	0.14	0.83
Total born	21.5	20.7	21.6	1.36	20.2	21.5	1.84	0.85	0.53
Live born piglets	20.6	19.9	21.3	0.98	19.0	20.9	1.26	0.57	0.20
Piglet birth weight, kg	1.17	1.17	1.08	0.05	1.00	1.17	0.06	0.30	0.02
Farrowing length, hours	5.85	4.45	6.60		4.35	5.82		0.24	0.25
95% confidence interval (CI)	[4.4; 7.8]	[3.3; 6.1]	[4.6; 9.5]		[2.8; 6.8]	[4.8; 7.1]			
Birth interval, min	10.7	8.90	11.3		10.1	10.3		0.34	0.93
95% CI	[8.7; 13.3]	[7.0; 11.3]	[8.8; 14.6]		[7.2; 14.2]	[8.8; 12.0]			
Colostrum yield, kg	6.9	6.7	6.6	0.39	5.2	7.1	0.53	0.85	<0.01
Piglet intake 0–24 h, g	370	347	357	13.7	302	370	18.5	0.41	<0.01
Piglet gain 0–24 h, g	67.1	57.8	74.4	14.2	42.5	71.2	18.2	0.68	0.17
Colostrum composition									
DM 0 h, %	26.9	28.5	27.7	0.87	28.2	27.5	1.11	0.36	0.59
Fat 0 h, %	4.67	5.42	4.62	0.40	5.42	4.79	0.52	0.21	0.28
Lactose 0 h, %	3.32	3.24	3.33	0.09	3.22	3.32	0.11	0.69	0.43
Protein 0 h, %	17.9	18.2	18.3	0.69	18.1	18.1	0.89	0.84	0.99
Casein 0 h, %	15.4	15.3	16.0	0.59	15.5	15.5	0.76	0.70	0.92
Energy 0 h, MJ/kg[2]	8.70	9.17	8.92	0.31	9.03	8.89	0.40	0.48	0.76
DM 24 h, %	19.8	19.0	20.4	0.75	21.3	19.3	0.96	0.43	0.08
Fat 24 h, %	7.14	6.58	7.39	0.71	8.83	6.62	0.91	0.68	0.04
Lactose 24 h, %	4.33	4.35	4.35	0.07	4.33	4.34	0.09	0.96	0.86
Protein 24 h, %	7.90	8.16	7.23	0.51	6.53	8.09	0.66	0.37	0.04
Casein 24 h, %	6.29	6.68	5.72	0.43	4.83	6.58	0.56	0.24	0.01
Energy 24 h, MJ/kg[2]	5.37	5.38	5.5	0.26	5.65	5.35	0.33	0.91	0.43

[a,b]Means with different superscript letters differ significantly ($P < 0.05$).

[1]Treatment.

[2]Time from last meal until the onset of farrowing.

[3]Milk energy was estimated from the content of fat, protein, and lactose in milk and their respective energy values (Weast, 1977).

($P < 0.001$). The concentration of plasma insulin, glucose, lactate, NEFA, and Triglycerides (**TAG**) did not differ among strategies. Plasma insulin and TAG was lowest at day 10 in lactation and highest at day 3 and 17 ($P < 0.001$). Plasma glucose increased from day 3 to day 17 ($P = 0.04$). Plasma NEFA was higher at day 3 and 10 in lactation than at day 17 ($P < 0.001$). Plasma urea was highest for sows fed the lactation diet and the transition diet until day 3, intermediate for sows fed the transition diet until day 10 and the gestation diet until day 3, and lowest for sows fed the gestation diet until day 10 ($P = 0.04$). Plasma urea increased from day 3 to day 17 in lactation ($P < 0.001$).

Milk fat at day 10 was positively correlated with BF at day 2 ($r = 0.29$; $P < 0.01$; Figure 2) and milk fat at day 17 tended to be positively correlated with BF at day 2 ($r = 0.18$; $P = 0.09$). Milk fat at day 3 and milk yield from day 3 to 10 were not correlated with BF at day 2.

Experiment 3. Total born piglets, live born piglets, frequencies of stillbirths and piglet diarrhea, and litter size at weaning did not differ between sows fed a gestation diet or a lactation diet (Table 7). Primiparous sows gave birth to less total born and live born piglets than multiparous sows ($P < 0.001$). Frequency of stillbirth was lower for primiparous sows compared with multiparous sows ($P < 0.01$). The frequency of piglet diarrhea was higher for first parity sows compared with multiparous sows ($P < 0.001$).

DISCUSSION

Impact of Late Gestation Feeding on Farrowing Performance

A transition diet may be formulated with, for example, high dietary fiber to achieve fast farrowing (Feyera et al., 2017) or high colostrum yield

Table 3. Initial parameters and sow plasma metabolites 3 d before parturition of sows fed a gestation diet, a transition diet, or a lactation diet from 6 d before parturition (experiment 2)

	Treatment				Parity			*P*-value	
Item	Gestation	Transition	Lactation	SEM	Primi	Multi	SEM	Trt[1]	Parity
Sows									
No. of sows	36	34	18		14	81			
Mean parity	2.6	2.5	2.4		1	2.8			
Initial BW day 111, kg	261	261	252	4.20	217	267	4.97	0.19	<0.001
Initial back fat day 111, mm	14.2	13.3	13.9	0.63	14.2	13.7	0.78	0.40	0.55
Feed intake, kg/d	3.05	2.96	2.99	0.04	2.99	3.00	0.05	0.07	0.84
Sow plasma metabolites									
Insulin, pmol/L	8.50	8.32	8.93	0.97	13.8	7.53	1.23	0.88	<0.001
Glucose, mM	5.13	4.97	5.16	0.13	5.45	5.00	0.16	0.37	0.01
Lactate, mM	1.78	1.91	1.98	0.20	2.29	1.79	0.24	0.68	0.07
NEFA, µekv/L[2]	32.3	74.2	55.0		28.4	55.4		0.06	0.15
NEFA CI	[20.1; 51.9]	[46.0; 120]	[28.4; 107]		[12.7; 63.9]	[40.0; 76.9]			
TAG, mM[3]	0.44	0.42	0.49	0.05	0.64	0.41	0.06	0.53	<0.001
Urea, mM	3.65[b]	3.88[b]	4.45[a]	0.12	3.81	3.92	0.15	<0.001	0.53

[a,b]Means with different superscript letters differ significantly ($P < 0.05$).

[1]Treatment.

[2]Nonesterified fatty acid is log-transformed before statistical analysis, and hence confidence limits are given in brackets instead of SEM values.

[3]Triglycerides.

Table 4. Sow and litter performance during lactation of sows fed a gestation, a transition diet, or a lactation diet from 6 d before parturition until day 3 or 10 in lactation and subsequent a lactation diet until weaning (experiment 2)

	Strategy						Parity			*P*-value	
	Gestation		Transition		Lactation						
	Day 3	Day 10	Day 3	Day 10							
Item	1	2	3	4	5	SEM	Primi	Multi	SEM	Str[1]	Parity
No of sows	18	18	18	18	18	-	15	75			
Sow initial BW day 2, kg	234	234	229	229	225	4.77	192	238	5.55	0.58	<0.001
Sow initial back fat day 2, mm	13.1	13.9	12.6	13.0	13.7	0.61	13.2	13.3	0.74	0.57	0.88
Sow initial body protein day 3, kg[2]	40.1	39.8	40.6	40.1	38.5	0.78	33.2	41.1	0.82	0.33	<0.001
Sow initial body fat day 3, kg[2]	41.8	42.3	35.7	40.0	36.9	2.20	31.1	40.9	2.34	0.09	<0.001
Sow ADFI day 2–24, kg/d	6.72	6.66	6.62	6.53	6.72	0.10	6.66	6.65	0.11	0.57	0.96
Sow BW loss day 2–10, kg	9.61	11.0	7.22	8.42	7.63	1.76	4.82	9.52	1.94	0.48	0.03
Sow BW loss day 2–24, kg	1.40	2.12	1.76	-3.05	0.52	2.55	−2.87	1.16	2.91	0.60	0.22
Sow back fat loss day 2–10, mm	0.47	0.66	0.78	0.59	0.5	0.15	0.51	0.61	0.18	0.59	0.60
Sow back fat loss day 2–24, mm	1.00	1.01	1.08	0.55	1.1	0.27	0.45	1.04	0.30	0.57	0.09
Sow protein mobilization day 3–10, kg/d	0.22	0.32	0.28	0.25	0.22	0.04	0.20	0.26	0.04	0.12	0.12
Sow fat mobilization day 3–10, kg/d	0.47	0.09	−0.22	0.09	−0.01	0.20	−0.50	0.20	0.21	0.10	<0.01
Calculated sow weight loss day 3–10, kg[2]	5.40	10.8	10.3	6.32	8.41	1.90	9.47	7.94	1.96	0.11	0.49
Sow milk yield day 3–10, kg/d[3]	8.78	8.48	9.02	7.96	8.84	0.64	8.66	8.61	0.73	0.79	0.95
Initial litter size day 2	14	14	14	14	14		14	14			
Initial litter weight day 2, kg	18.8	18.7	18.2	17.7	18.9	0.69	17.2	18.7	0.81	0.68	0.09
Litter size at weaning day 24	12.6	12.6	12.8	11.9	12.8	0.33	13.1	12.4	0.37	0.30	0.13
Piglet ADG day 2–10, g/d	154	153	172	156	167	7.98	161	161	9.14	0.30	1.00
Piglet ADG day 2–24, g/d	197[ab]	203[ab]	214[a]	182[b]	207[ab]	7.35	181	204	8.36	0.04	0.02
Litter gain day 2–24, kg/d	2.53[ab]	2.58[ab]	2.62[ab]	2.19[b]	2.65[a]	0.11	2.32	2.55	0.13	0.04	0.11

[a,b]Means with different superscript letters differ significantly ($P < 0.05$).

[1]Strategy.

[2]Estimated body pools of fat and protein from Rozeboom et al. (1994).

[3]Estimated milk yield from Theil et al. (2002).

Table 5. Energy, N, and Lys metabolism from day 3 to 10 in sows fed a gestation, a transition diet, or a lactation diet from 6 d before parturition until day 3 or 10 in lactation and subsequent a lactation diet until weaning (experiment 2)

	Strategy						Parity			*P*-value	
	Gestation		Transition		Lactation						
	Day 3	Day 10	Day 3	Day 10							
Item	1	2	3	4	5	SEM	Primi	Multi	SEM	Str[1]	Parity
Energy metabolism											
GE intake, MJ/d	77.3	74.3	78.0	75.2	76.3	1.44	77.3	76.1	1.61	0.34	0.48
ME intake, MJ/d	59.3^{ab}	55.6^{b}	60.0^{a}	57.2^{ab}	58.8^{ab}	1.11	59.1	58.1	1.24	0.04	0.46
Maintenance, MJ/d	28.3	28.3	28.0	28.0	27.6	0.42	24.7	28.7	0.48	0.73	<0.001
Milk E output, MJ/d	41.1	43.2	43.8	39.9	44.0	2.99	43.2	42.2	3.41	0.80	0.78
Milk E output relative to ME intake, %	69.1	78.4	74.3	71.5	75.8	5.71	73.3	73.8	6.4	0.77	0.95
Total heat production, MJ/d	40.3	40.9	40.8	39.6	40.5	0.97	37.3	41.0	1.10	0.88	<0.01
Energy retention, MJ/d	−21.3	−28.6	−24.0	−22.8	−25.3	4.24	−21.4	−24.9	4.74	0.76	0.51
NEc in feed, MJ/kg[1]	10.5	9.67	10.3	10.3	10.3	0.22	10.2	10.2	0.24	0.07	0.94
NEc:ME	80.5	77.9	79.0	79.8	78.6	1.61	79.3	79.2	1.80	0.77	0.95
N metabolism											
N intake, g/d	119^{a}	93.7^{c}	121^{a}	107^{b}	120^{a}	2.32	114	112	2.59	<0.001	0.38
SID N intake, g/d	100^{a}	75.1^{c}	102^{a}	88.0^{b}	101^{a}	1.97	95.4	93.1	2.20	<0.001	0.37
Urine N output, g/d	30.0^{a}	17.0^{c}	31.0^{a}	23.4^{b}	31.1^{a}	0.63	27.3	26.5	0.71	<0.001	0.30
Milk N output, g/d	81.9	81.6	82.0	75.4	81.3	5.52	79.9	80.5	6.26	0.90	0.93
Milk N output relative to total N intake, %	69.5	87.4	68.7	71.5	68.6	5.60	70.2	73.5	6.26	0.08	0.63
Milk N output relative to SID N intake, %	82.9^{b}	109^{a}	81.8^{b}	85.0^{ab}	81.1^{b}	6.66	84.3	88.4	7.56	0.02	0.63
Nitrogen retention, g/d	−12.0	−24.0	−10.6	−11.2	−11.2	5.99	−12.0	−14.0	6.69	0.44	0.79
Corrected milk N utilization, % of SID N intake[2]	76.6^{a}	69.3^{b}	76.9^{a}	76.0^{ab}	77.1^{a}	1.88	76.2	75.1	2.13	0.02	0.63
Corrected milk N utilization, % of total N intake[2]	64.4^{a}	55.5^{b}	64.8^{a}	62.8^{a}	65.1^{a}	1.56	63.4	62.4	1.77	<0.001	0.61
Lys metabolism											
Lys intake, g/d	40.8^{a}	28.5^{c}	42.9^{a}	35.7^{b}	43.2^{a}	0.94	39.2	38.2	1.05	<0.001	0.39
SID Lys intake, g/d	35.6^{a}	23.6^{c}	37.7^{a}	30.7^{b}	38.0^{a}	0.86	34.0	33.1	0.96	<0.001	0.39
Maintenance, g/d	2.72	2.71	2.69	2.68	2.65	0.04	2.37	2.75	0.05	0.73	<0.001
Milk Lys output, g/d	36.6	36.5	36.7	33.7	36.4	2.47	35.7	36.0	2.80	0.90	0.93
Milk Lys output relative to total Lys intake, %	91.5^{b}	128^{a}	87.3^{b}	95.3^{b}	84.9^{b}	7.39	93.1	97.9	8.25	<0.001	0.60
Milk Lys output relative to SID Lys intake, %	105^{b}	154^{a}	100^{b}	109^{b}	96.3^{b}	8.45	108	113	9.60	<0.001	0.59
Lysine retention, g/d	−7.52	−19.4	−5.35	−8.57	−4.60	2.88	−7.67	−9.24	3.28	<0.01	0.67
Corrected milk Lys utilization, % of SID Lys intake[3]	89.6^{a}	84.7^{b}	90.1^{a}	89.0^{a}	90.5^{a}	0.85	89.3	88.7	0.95	<0.001	0.59
Corrected milk Lys utilization, % of total Lys intake[3]	78.0^{ab}	70.1^{c}	79.0^{ab}	76.5^{b}	79.7^{a}	0.75	77.2	76.7	0.84	<0.001	0.57

[a,b,c]Means with different superscript letters differ significantly ($P < 0.05$).

[1]Strategy.

[2]Milk N utilization corrected for mobilization was calculated by correcting for N being mobilized from sow muscle mass, calculated as SID or total N intake minus milk N output and milk N utilization (assuming an efficiency of N for milk production of 0.78 Strathe, 2017).

[3]Milk Lys utilization corrected for mobilization was calculated by correcting for Lys being mobilized from sow muscle mass, calculated as SID or total Lys intake minus milk Lys output and milk Lys utilization (assuming an efficiency of Lys for milk production of 0.91; Strathe, 2017).

(Theil et al., 2014). However, many farmers do not at present use a transition diet, and those that do often uses a simple transition diet, obtained by mixing gestation and lactation feed in a fixed ratio. In the present study, no evidence of impact of feeding sows a gestation diet, a simple transition diet (50/50% mix) or a lactation diet was found on farrowing length, which on average lasted for 4.45 to 6.60 h for the three dietary treatments. The farrowing length in the current study is comparable

Table 6. Milk composition and blood metabolites for sows fed a gestation, a transition diet, or a lactation diet from 6 d before parturition until day 3 or 10 in lactation and subsequent a lactation diet until weaning (experiment 2)

	Strategy						Day				*P*-value	
	Gestation		Transition		Lactation							
	Day 3	Day 10	Day 3	Day 10								
Item	1	2	3	4	5	SEM	3	10	17	SEM	Str[1]	Day
Milk composition												
Milk DM, %	18.0	17.6	17.9	18.3	18.1	0.27	19.1^{A}	17.4^{B}	17.5^{B}	0.19	0.33	<0.001
Milk fat, %	7.00	7.00	7.00	7.32	7.14	0.27	8.12^{A}	6.55^{B}	6.61^{B}	0.18	0.87	<0.001
Milk protein, %	5.19	5.09	5.15	5.37	5.26	0.08	5.81^{A}	4.88^{B}	4.95^{B}	0.06	0.09	<0.001
Milk casein, %	4.10	4.02	4.05	4.15	4.11	0.07	4.49^{A}	3.86^{B}	3.91^{B}	0.04	0.68	<0.001
Milk lactose, %	5.10	5.07	5.10	5.02	5.03	0.03	4.87^{B}	5.15^{A}	5.18^{A}	0.02	0.12	<0.001
Milk energy, MJ/kg[2]	4.62	4.54	4.59	4.69	4.76	0.07	4.94^{A}	4.47^{B}	4.52^{B}	0.06	0.08	<0.001
Plasma metabolites												
Insulin, pmol/L	23.8	18.0	20.5	22.2	22.0	1.88	25.1^{A}	16.7^{B}	22.2^{A}	1.28	0.23	<0.001
Glucose, mM	5.07	4.92	5.07	4.85	5.10	0.11	4.91^{B}	4.97^{AB}	5.13^{A}	0.09	0.27	0.04
Lactate, mM	1.43	1.32	1.32	1.41	1.29	0.09	1.32	1.36	1.39	0.06	0.74	0.62
NEFA, µekv/L[4]	68.6	59.7	90.2	77.2	90.5		51.1^{A}	81.5^{A}	106^{B}		0.53	<0.001
NEFA CI	[54.8; 85.8]	[47.1; 75.6]	[70.8; 115]	[60.9; 97.7]	[72.1; 114]		[43.4; 60.2]	[69.3; 95.9]	[89.7; 124]			
TAG, mM[5]	0.18	0.20	0.21	0.23	0.22	0.02	0.24^{A}	0.14^{B}	0.25^{A}	0.01	0.09	<0.001
Urea, mM	4.23^{ab}	4.09^{b}	4.50^{a}	4.35^{ab}	4.51^{a}	0.12	3.93^{C}	4.40^{B}	4.66^{A}	0.08	0.04	<0.001

[a,b]Means with different superscript letters differ significantly ($P < 0.05$).

[A,B,C]Means with different superscript letters differ significantly ($P < 0.05$).

[1]Strategy.

[2]Milk GE was estimated from the content of fat, protein, and lactose in milk and their respective energy values (Weast, 1977).

[3]Utilization of N and GE relative to intake.

[4]Nonesterified fatty acid is log-transformed before statistical analysis, and hence confidence limits are given in brackets instead of SEM values.

[5]Triglycerides.

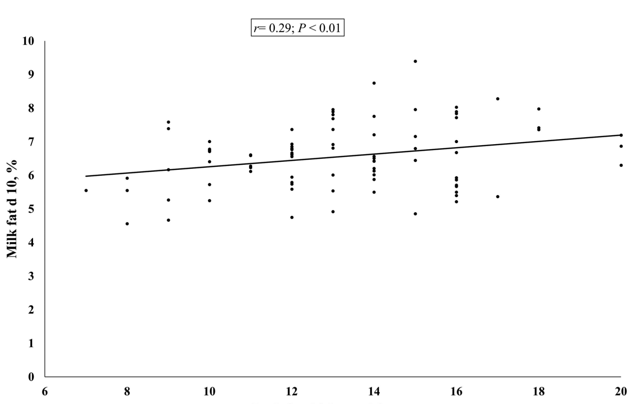

Figure 2. Pearson correlation between back fat (**BF**) thickness day 2 and fat percent in milk at day 10 in lactation (across all strategies; $n = 90$).

with the results obtained from seven different Danish experiments, which has been summarized by Feyera et al. (2018), and showed a mean farrowing length of 5.8 ± 2.7 h. In a study by Tydlitát et al. (2008), it was observed that increasing dietary CP from 13.4 to 21.0%, gradually increased the farrowing length from 4.48 to 8.62 h and this concomitantly increased the stillbirth rate from 8.8% to 19.8%. The dietary CP in the current study only increased from 13.1% (gestation diet) to 16.7% CP (lactation diet), which probably along with a fairly low number of sows per treatment explains the absence of statistical difference in farrowing length. Sows fed the transition diet did, however, have a numerically shorter farrowing length and shorter birth interval and this could be associated with a greater energy supply from fibers as compared with the gestation diet (Feyera et al., 2018) and less oxidation of excess dietary protein and hence a higher energy utilization as compared with the lactation diet (Pedersen et al., 2019b).

Feeding of sows in the last week of gestation did not have any impact on piglet birth weight or total born piglets. The mean piglet weight at birth

Table 7. Total born, live born, stillbirth rate, frequency of piglet diarrhea, and litter size at weaning of sows fed a gestation diet or a lactation diet from 6 d before parturition (experiment 3)

	Strategy			Parity			*P*-value	
	Gestation	Lactation						
Item	1	5	SEM	Primi	Multi	SEM	Trt[1]	Parity
No. of sows	63	61		22	102			
Mean parity	2.6	2.5		1	2.9			
Total born	20.7	20.9	0.45	17.6	21.5	0.80	0.77	<0.001
Live born piglets	18.9	18.9	0.38	17.2	19.3	0.70	0.95	0.01
Stillbirth rate, %	6.64	6.82		4.44	9.57		0.63	<0.01
	[5.4; 8.1]	[5.6; 8.3]		[2.7; 7.1]	[8.4; 10.9]			
Litter size day 2	14	14		14	14			
Frequency of piglet diarrhea, %	18.3	21.2		25.5	14.9		0.17	<0.001
	[15.3; 21.7]	[17.9; 24.9]		[20.4; 31.4]	[13.0; 17.1]			
Litter size at weaning day 24	12.7	12.8	0.15	12.9	12.7	0.27	0.52	0.50

[1]Treatment.

varied from 1.08 to 1.17 kg and sows gave birth to 20.7 to 21.6 piglets. The birth weight in the current study was lower than what has been found previously in five Danish studies (Vadmand et al., 2015), where mean piglet birth weight ranged from 1.21 to 1.44 kg. In the studies reported by Vadmand et al. (2015), sows gave birth to a lower number of piglets (15.8 to 18.7 total born piglets) than in the present study, which could explain why piglets were lighter in the present study. This is further supported by Quiniou et al. (2002) who found a significant decrease in piglet birth weight from 1.59 to 1.26 kg when the litter size increased from 9 to 17 piglets. In addition to the high number of total born piglets, multiparous sows in the current study produced on average 7.1 kg colostrum, which is higher than previous studies (Vadmand et al., 2015), but in spite of the high colostrum yield, the colostrum intake of piglets was fairly low due to the very high litter size.

Impact of Sow Parity on Colostrum and Plasma Insulin

Primiparous sows had a lower colostrum yield than multiparous sows (5.2 vs. 7.1 kg). In line with that, Devillers et al. (2007) reported that colostrum yield of primiparous sows tended to be lower than colostrum yield of second and third parity sows. The chemical composition of colostrum was comparable for primiparous and multiparous sows at parturition (0 h). After 24 h, however, colostrum fat of primiparous sows was greater, while protein and casein was lower as compared with multiparous sows. In support of this, Craig et al. (2019) found the same numerical trend in colostrum protein and fat content as observed in the current study. These results indicate that even though the colostrum production is of high priority to the sow, primiparous sows either utilized or prioritized the dietary nutrients differently than the multiparous sows. The parity effect on colostrum composition at 24 h underline that the majority of colostrum is produced after birth of first piglet, which was recently shown by Feyera et al. (2019) in a study where mammary uptake of nutrients was compared with colostrum output.

Primiparous sows had a higher plasma insulin and glucose concentration than multiparous sows, before parturition. At the same time, primiparous sows had a lower BW than multiparous sows, but followed the same feeding curve. Consequently, primiparous sows were fed 1.5-fold above their maintenance requirement, whereas multiparous sows were fed approximately 1.3-fold above, and this likely explains the higher plasma insulin. Another possible explanation of the higher plasma insulin concentration could be due to a higher insulin resistance of primiparous sows at the end of pregnancy, as reported by Pere and Etienne (2007). Additionally, piglets from primiparous sows had a higher frequency of diarrhea than piglets from multiparous sows. The higher insulin concentration in plasma, higher frequency of piglet diarrhea, and lower colostrum yield of primiparous sows emphasize the need for developing distinct feeding strategies for primiparous as compared with multiparous sows in late gestation, which was also suggested by Goncalves et al. (2016) to maximize performance of sows approaching farrowing.

Impact of Feeding During the Transition Period on Lactation Performance

Feeding of sows in the transition period from late gestation to early lactation is a complex matter. It is not known when it is appropriate to shift from a low CP gestation diet to a high CP lactation diet, neither is it known how such a diet optimally should be composed (Theil, 2015). The high plasma urea concentration observed before parturition for sows fed the lactation diet suggests that these sows were fed excess CP before parturition. However, no differences in overall lactation performance were observed, and this may partly be due to the high dietary protein in the gestation and transition diets. Another explanation for not observing any differences among dietary strategies is likely due to the low lactation performance of all sows in the herd. Litters from sows fed the transition diet until day 10 of lactation had a lower litter gain and ADG. The lower litter gain was most likely not related to the dietary strategy, since sows receiving the lowest CP diet (gestation diet) until day 10 of lactation was challenged even more than sows fed the transition diet until day 10 of lactation, but the ADG of these litters were similar to the other three strategies. Possibly the lower litter gain observed for sows fed transition diet until day 10 could be ascribed to the lower litter weight at day 2 and lower litter size at weaning (numerical differences), because both may reduce milk production and litter gain as reported by Strathe et al. (2017). Overall, the daily litter gain was fairly low (2.19 to 2.65 kg/d) when comparing with recent studies on hyper-prolific sows (3.2 to 3.3 when supplied optimally with CP; Pedersen et al., 2019a, Hojgaard et al., 2019), indicating that the sow milk yield was compromised. In further support of a poor milk yield, the sows indeed gained BW from day 10 and up until weaning. In our conditions (high CP in gestation diet; poor milk yield; restricted feeding in early lactation), no evidence of dietary effects on sow performance was observed.

Feed Efficiency and Nutrient Balances

The hypothesis was that feeding sows a transition diet during the transition period would improve the utilization of feed in late gestation and in early lactation. However, the dietary strategies showed no evidence of effects on energy, N or Lys output in milk from day 3 to 10 of lactation. Sows secreted on average 42 MJ energy, 80 g N, and 36 g Lys daily in milk from day 3 to 10 of lactation, which is considerably less than what has been found in a recent Danish study with high performing sows. In that study, sows fed increasing dietary protein from 11.8% to 15.6% SID CP secreted on average 56 MJ energy and 95 g N in milk daily during the first wk (day 4 to 11) of lactation, respectively (Pedersen et al., 2019a, 2019b). The milk N secretion in the current study is, however, higher than what has been reported in the study of Huber et al. (2015), where sows secreted 49 to 57 g N in milk from day 3 to 7 of lactation.

Sows fed a gestation diet until day 3 followed by a lactation diet until weaning were able to utilize as much as 10.5 MJ/kg from the feed, when corrected for energy mobilization (NEc). This is comparable to that reported for sows fed optimally with dietary CP (12.8% SID CP; Pedersen et al., 2019b). In contrast, sows fed the gestation diet until d 10 of lactation in the current study only utilized 9.7 MJ/kg which is 6% to 8% lower than sows fed the other strategies. This drop in feed utilization is economically unfavorable, and a 1% drop in feed utilization would correspond to a loss of €3.4 million annually to Danish pig producers. This indicates that sows in the current study utilized the feed efficiently, except sows that were fed the gestation diets until day 10. The latter may be due to insufficient Lys supply, whereby protein is mobilized and the remaining AA that were mobilized along with lysine were likely oxidized, causing a depressed energy utilization as reported for excess dietary CP (Pedersen et al., 2019b).

Sow Body Condition

Sows in the current experiment had an average BF thickness of 12.6 to 13.9 mm at day 2 in lactation and a body fat pool of 34 to 42 kg, which is rather low compared to other Danish studies. In the study of Pedersen et al. (2019b) and Pedersen et al. (2019a), sows had a BF thickness of 14.2 to 16.7 mm at day 2 in lactation and a body fat pool of 67 to 72 kg, respectively. The poor body condition of sows in the current study was likely part of the reason why sows had a low lactation performance (litter gain). In support, Kim et al. (2015) reported in a study with 11,536 sows, that sows with a BF thickness of 17 to 18 mm had the greatest litter weight gain, and that litter weight gain dropped by up to 11% for sows with low BF. Strathe et al. (2017) reported a positive correlation between piglet ADG and BF loss, and these findings suggest that sows in the current study likely were not able to mobilize enough fat. In support of this, sow's BF thickness at day 2 was found to be positively correlated with milk fat on day 10 (Figure 2) and tended to be positively correlated on day 17. At day 3, however, sows were able to mobilize enough body fat to synthesize milk of similar fat content irrespective of BF.

CONCLUSION

Results from the current study indicated that sows were oversupplied with dietary CP in late gestation, when fed a lactation diet, although the performance was not compromised. This study was not able to determine when sows ideally should shift from a simple transition diet to a high CP lactation diet, likely due to a low lactation performance. This study indicated that primiparous and multiparous sows should either be fed different amounts of feed or different feed composition.

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