Effect of feeding frequency and sow parity based on isocaloric intake during gestation on sow performance

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ABSTRACT: The aim of this study was to investigate the effect of feeding frequency and sow parity based on same rate of maintenance energy intake during gestation on sow performance. One hundred and seventy-seven sows [Topigs Norsvin 70, Landrace × Large White, Topigs Norsvin USA, Burnsville, MN; parity 3.80 ± 0.16 ; initial BW = 211.34 ± 3.37 kg; backfat (BF) 13.57 ± 0.54 mm] were blocked by parity, balanced for BW, and randomly assigned to 1 of 3 treatments in a randomized complete block design. Treatments included sows fed corn–soybean meal-based diet 1× daily at 0730 h (control, T1), 2× daily [half ration at 0730 and 1530 h (T2)], or 3× daily [a third portion at 0730, 1130, and 1530 h (T3)], with daily feed quantity kept at $1.25 \times$ maintenance energy intake [$100 \times (\text{BW})^{0.75}$] kcal ME/d. Treatments were imposed from day 30 of gestation. Sows received on average 6,921, 7,129, and 7,399 kcal ME/d from days 30 to 60, days 61 to 90, days 91 to 109 of gestation, respectively. Feeding frequency during gestation had no effect on lactation ADFI ($P > 0.10$). Sows fed 3× daily during gestation had improved lactation G:F ($P = 0.040$) compared with sows fed 2× but similar to control sows ($P = 0.338$). Treatment did not alter BW

or BW variations during gestation, lactation, or from days 30 to wean ($P > 0.10$). Sows fed 2× daily had tendency to gain BF from day 30 to day 109 of gestation ($P = 0.053$) but tended to lose BF during lactation ($P = 0.091$) relative to the control sows. Feeding frequency (2× and 3× daily) tended to increase the number of piglets weaned by 0.40 ($P = 0.056$) and 0.53 ($P = 0.098$) piglets, respectively, compared with control sows. Sows fed 2× daily during gestation had reduced number of stillborn relative to control sows ($P = 0.035$). From day 30 to wean, gilts had propensity to lose BF relative to P1+ ($P = 0.094$), but lost BF compared with P3+ and P6+ sows ($P = 0.003$). Parity P6+ sows had highest percentage of both 72 h and preweaning piglet mortality than P0, P1+, and P3+ sows ($P < 0.05$). In conclusion, parity (P6+) had greater lactation BW gain but higher mortalities relative to lower parity sows. Sows fed 2× daily tended to gain BF from days 30 to 109 of gestation and had reduced number of stillborn relative to control sows. It appears that increasing gestation sow feeding frequency from 1× daily to 2× and 3× daily may reduce the number of stillborn and increase litter size at weaning although most of the reproductive traits were not affected.

Key words: body weight, feeding frequency, isocaloric intake, pregnant sow, sow parity, sow performance

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INTRODUCTION

The practice of feeding frequency in pregnant sows and its carryover effect in lactation are extensively studied using different approaches

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and methodologies to evaluate objectives such as increasing fetal fatty acids (Williams et al., 1979), reduction in labor cost of feeding (Michel et al., 1980), improving sow reproductive performance (Wittman, 1986), enhancement of nutrient utilization (Holt et al., 2006), and improvement in animal welfare (Jensen et al., 2012). However, feeding frequency results on performance have been contradictory in pregnant gilts and sows. Schneider et al. (2007) reported that gilts fed 6 times daily during gestation tended to have greater ADG and higher born alive piglets than gilts fed 2 times daily, but this response was not observed in sows. Similarly, Michel et al. (1980) and Wittman (1986) indicated that increasing the feeding frequency of gilts and sows resulted in greater number of born alive piglets. On the contrary, others did not elicit a response of feeding frequency on sow performance traits (Douglas et al., 1998; Holt et al., 2006; Jensen et al., 2012). Lack of standardization of energy intake among sow feeding frequency studies has resulted in conflicting reports. For instance, Michel et al. (1980), Holt et al. (2006), Schneider et al. (2007), and Jensen et al. (2012); fed 1.9, 1.88, 2.5, and 2.6 kg corn-soybean or barley-soybean meal-based diets to provide daily energy intake of 6,371, 6,200, 8,140, and 8,362 kcal of ME/d, respectively, during gestation. A procedure is required to standardize the experimental dietary level of the energy intake among experiments. Utilizing kilogram live BW^{0.75} at days 30, 60, and 90 to adjust the level of energy intake during gestation enables the standardization of the ME intake. Therefore, the objective of this study was to investigate the effect of feeding frequency and sow parity given similar energy intake per kilogram live BW^{0.75} during gestation on sow performance.

MATERIALS AND METHODS

Animals, Housing, and Management

The study was conducted at the sow unit of University of Minnesota - Southern Research and Outreach Center, Waseca, MN. University of Minnesota Institutional Animal Care and Use Committee (IACUC) approved the protocol used in the study. Five contemporary groups of Topigs Norsvin sows (Landrace × Large White); total $N = 177$; initial average BW 210.12 ± 3.93 kg; and average parity of 3.8 ± 0.13 (range 0 to 9).

A total of 177 multiparous and nulliparous sows from 5 contemporary groups were used in the study. Sows were kept in gestation stalls with fully slatted

floors measuring (2.1 m × 0.59 m × 0.97 m) under temperature-controlled environment (22 ± 1 °C). Sow BW and backfat (BF) depth were recorded on day 30 of gestation prior to feeding. Backfat depth was measured at the last rib and 0.55 m from the dorsal midline using an ultrasound scanner (Leanmeater, Renco Corp., Minneapolis, MN) on both the left and right side and averaged. Gilts and sows were artificially inseminated at onset of standing estrus and repeated 24 h later using fresh diluted semen from Duroc boar (Compart Boar Store, Nicollet, MN).

Sows pregnancy status was confirmed on day 35 after inseminations with the aid of ultrasonic pregnancy checker (Classic Medical Supply, Inc., Florida). The conception rate was 88.9% for the 5 contemporary groups. Water was available on an ad libitum basis to sows through nipple drinker in stalls. On day 109 of gestation, sows were washed, moved to environmentally controlled farrowing rooms, and placed in individual farrowing stalls (2.13 m × 0.97 m × 0.66 m). Sows were fed the lactation diet of 2.27 kg (32.84 MJ ME/d) once per day irrespective of treatments until farrowing. After parturition, sows were fed twice daily at about 0800 and 1430 h. Lactation feed offered was weighed and marked on individual sow card during feeding and the amount of feed offered increased gradually to allow for ad libitum feed intake but preventing feed accumulation in feeders. Surplus feed from each crate was weighed and recorded at weaning. Litter size was equalized within 24 h postpartum through cross-fostering to approximately 12 pigs per litter within treatment.

The farm standard management processing procedures of piglets include intramuscular injection of 1 mL iron dextran shots, tail docking, cutting, and disinfection of naval cords within 24 h post-farrow. Room temperature was maintained at 24 ± 2 °C except at farrowing when supplemental heat lamp provided source of heat for piglets after birth for 48 h while they had access to floor heat pads. No creep feed was provided but piglets had access to the dam's feed. Male piglets surgically castrated between 5 and 8 d of age and all piglets vaccinated against porcine circovirus disease 4 d prior to weaning. Weaning occurred between 0800 and 1000 h at day 19 ± 0.25 postpartum. At weaning, sow BW and ultrasound BF thickness were recorded before transferring them to stalls for daily estrus detection using a mature boar housed in Contact-O-Max boar cart (Hog Slat Inc., Newton Grove, NC). Estrus was recorded when sows exhibited standing heat on exposure to the mature

boar and estrous interval from weaning calculated. Culling reason of sows included failure to conceive after second mating, anestrus exceeding 8 d postweaning, consecutive abortions, and difficulty to carry body weight on limbs. An amount of 2 kg (28.3 MJ ME/d) of gestation feed was offered once a day in stalls to sows and gilts from weaning through breeding to 30 d, which is considered optimal during that phase.

Experimental Design, Dietary Treatments, and Feed Line Calibration

Sows were blocked by parity, breeding date, and balanced for body weight, and randomly allocated to 1 of 3 treatments of feeding frequency with 11 to 12 replicates per batch in completely randomized block design. All contemporary groups of sows received a common corn–soybean meal-based diet during gestation and lactation. Nutrient specifications (Table 1) met or exceeded NRC (2012) nutrient requirements for gestating and lactating pigs. Dietary treatments were imposed from 30 d of gestation until day 109 of gestation following the procedures of Michel et al. (1980). Amount of feed fed from days 30 to 60, days 61 to 90, and days 91 to 109 of gestation was adjusted using body weights on days 30, 60, and 90, respectively. Daily ME intake was standardized using live metabolic BW ($BW^{0.75}$) based on recommendations of Le Naou et al. (2014) and fed at 1.25 times (Prunier and Quesnel, 2000) the maintenance requirements for sows ($100 \times BW^{0.75}$ kcal ME/d; NRC, 2012). On average, sows received 28.96, 29.83, and 30.96 MJ ME/d during the first, second, and third trimester of gestation, respectively. To provide the desired daily energy intake, sows received on average 2.17 kg (28.96 MJ ME/d), 2.24 kg (29.89 MJ ME/d), and 2.32 kg (30.96 MJ ME/d), from days 30 to 60, days 61 to 90, and days 91 to 109 of gestation, respectively. Sows were fed individually by raising the feeder ball valve of an Accu-Drop feed dispenser (AP Systems, Assumption, IL) to drop the required amounts of feed into the feeding troughs. The Accu-Drop feed dispensers were calibrated on days 30, 61, and 91 at various set points and related the volume of feed dispenser (Y , cm^3), to kilogram weight of feed (x) delivered as $Y = 5.4864x + 1.9087$; $R^2 = 0.9892$ (Fig. 1). The required daily full allowance of feed was provided once (1 $\times$) daily at: 0730 h (control, T1), twice (2 $\times$) daily (half ration each at 0730 and 1530 h, T2), or thrice (3 $\times$) daily (a third portion of ration allotment at 0730, 1130, and 1530 h, T3).

Table 1. Composition and nutrient analysis of gestation and lactation diets, as fed basis¹

Ingredients, %	Gestation diet	Lactation diet
Yellow dent corn	65.35	61.28
Soybean meal, dehulled, solvent extracted	10.00	17.20
Corn DDGS ² , >6% and <9% oil	20.00	15.00
Choice white grease	1.50	3.00
Dicalcium phosphate	1.20	1.15
Limestone, ground	1.00	0.88
Sodium chloride	0.35	0.35
L-Lys-HCl	0.10	0.46
L-Thr	-	0.13
DL-Met	-	0.01
L-Trp	-	0.04
Swine breeder premix ³ (EB Plus)	0.50	0.50
Total	100.00	100.00
Analyzed composition		
DM, %	89.34	89.60
GE, kcal/g	4,431	4,576
CP, %	15.70	17.90
NDF, %	13.30	12.00
ADF, %	4.80	4.50
Calculated nutrient composition		
SID metabolizable energy (ME), kcal/kg	3,379	3,456
SID Lys, %	0.58	1.03
SID Met, %	0.26	0.28
SID Met + Cys, %	0.48	0.53
SID Thr, %	0.45	0.65
SID Trp, %	0.12	0.19
Total available P	0.61	0.61
Ca, %	0.70	0.66
Crude fat, %	6.30	7.40
SID Lys/ME, g/Mcal	1.71	2.96

¹Mineral and vitamin mixture supplied per kilogram of diets: 15 mg of Cu (as $CuSO_4$); 124 mg of Fe (as $FeSO_4 \cdot 7H_2O$); 40 mg of Mn (as MnO); 124.7 mg of Zn (as ZnO); 2.2 mg of I (as $Ca(IO_3)_2$); 0.30 mg of Se (as Na_2SeO_3); 11,000 IU of vitamin A; 2,750 IU of vitamin D3; 55 IU of vitamin E; 4.4 mg of vitamin K3; 1.1 mg of thiamine; 9.9 mg of riboflavin; 55 mg of nicotinic acid; 33 mg of d-pantothenic acid; 2.2 mg of pyridoxine; 0.06 mg of vitamin B12; 2.6 mg of folic acid; 0.22 mg of biotin; and 1.92 mg of Na.

²Dried distiller's grains with solubles.

³Swine breeder premix was supplied by Agric-Nutrition Services, Inc., Shakopee, MN.

Collection of Sow Performance and Reproductive Data

Data about sow performance and reproductive parameters were recorded during gestation and lactation, respectively. This includes total born piglets, live born piglets, birth weight, number of stillbirths, count of mummified fetuses, number weaned, weaning weight, and return to estrous interval. Sow BW and BF depth were recorded on days 30, 60, 90, and 109 of gestation, within 24 h of farrowing, and

Figure 1. Calibration of Accu-Drop feed dispenser (AP Systems, Assumption, IL). Relationship between hopper volume (Y) of Accu-Drop feed dispenser and feed weight (x): $Y = 5.4864x + 1.9087$, $R^2 = 0.9892$. Feed drops were adjusted on day 30, 61, and 91 based on the BW of pigs on day 30, 60, and 90 of gestation, respectively.

at weaning. These gestational stages were selected as they represent completion of placentation process (day 30), midpoint of a period of high fetal death due to intrauterine competition (day 60), a period of rapid fetal demands for nutrients (day 90), and a point close to farrowing (day 109) (Mesa et al., 2012). Approximately 35 sows farrowed per batch from 5 contemporary groups and piglets from these sows were weighed within 24 h of farrowing. To study the effect of parity, sows were grouped into 1 of 4 categories as of day 109 of gestation. Parity categories were defined as parity 0 = pregnant gilts that had not produced a litter ($n = 25$), parity 1+ = first and second parity sows ($n = 46$), parity 3+ = third to fifth parity sows ($n = 54$), and parity 6+ = sixth to ninth parity sows ($n = 52$), modified from Rootwelt et al. (2013). Lactation feed disappearance was calculated as the difference between the total feed offered and surplus feed not consumed on the day of weaning. Sow lactation feed efficiency was calculated as summation of sow BW loss (or gain) and litter weight gain relative to feed disappearance (Rosero et al., 2012). Sow and piglet preweaning mortality events were recorded daily.

Chemical Analysis

Feed samples were analyzed for DM, GE, CP, NDF, and ADF. Dry matter content of feeds was determined by the oven-drying method (method 934.01; AOAC, 2006). Gross energy was determined by basic bomb calorimeter (IKA Werke GmbH and Co. KG, Staufen, Germany) with benzoic acid in the samples being used as calibration. The CP content ($N \times 6.25$) in the basal diet was determined using Kjeldahl method (method

984.13, AOAC, 2006; Kjeltex 2300 Analyzer, Foss, Höganäs, Sweden). Determination of crude fat was by ether extract (method 920.39; AOAC, 2006) using an ANKOM XT15 extraction system (ANKOM Technology, Macedon, NY). The NDF and ADF content were determined using filter bag technique (ANKOM 2000 fiber analyzer, method 12 and 13; ANKOM Technology, Macedon, NY) (methods 973.18 and 973.19; AOAC, 2006). To determine the total ash content, samples of basal diet were ashed in a high temperature muffle furnace at 600 °C for 6 h (Isotemp Muffle Furnace, Thermo Fisher Scientific Inc., Hampton, NH).

Statistical Analysis

All data were checked for normality using PROC UNIVARIATE procedure of SAS (SAS Inst., Inc., Cary, NC). The data sets (born alive piglets, mummified fetuses, and number of stillborn) were analyzed as discrete binomial proportions using PROC GENMOD procedure of SAS. The ILINK option of SAS was used to determine least squares means and SE of the proportions. Other count and continuous data were analyzed as a randomized complete block design using PROC GLIMMIX with Poisson distribution and PROC MIXED procedures, respectively. When interactions are not significant, they were removed from the model and the final statistical model included fixed effects of treatment and parity; block was random effect with sow as the experimental unit in all analyses.

The repeated measures model for sow BW, BF, BW changes, and BF changes included fixed effects of treatment (feeding frequency), parity, gestation day, treatment $\times$ gestation day interaction, parity $\times$ gestation day interaction, and treatment $\times$ parity $\times$ gestation day interaction, whereas block was considered a random effect. Sow BW and BF at day 30 were used as covariate in the repeated measures model. Autoregressive process of first order was used to model repeated observation within sow as covariate structure (Littell et al., 1998). Least squares means of fixed effects with their corresponding SE were calculated using the LSMEANS statement of SAS. The estimation method was based on residual maximum likelihood (REML). Data are presented as means $\pm$ SEM. Difference between least squares means was requested using PDIF of SAS and significant differences were declared at $P \leq 0.05$ while a trend was considered between $0.05 < P \leq 0.10$. The Tukey–Kramer's adjustment method for multiple comparisons was used for means separation.

RESULTS

No two- or three-way significant interactions were observed for any sow performance traits measured ($P > 0.10$) except that gilts fed 3× daily during gestation had improved lactation feed efficiency compared with those fed 2× daily (0.321 vs. 0.524; $P = 0.014$).

Effects of Feeding Frequency and Parity on Sow BW and BF under Isocaloric Condition per Kilogram Live BW^{0.75}

Feeding frequency (either 2× or 3×) did not influence sow BW and BW variations in gestation, lactation, or from day 30 to wean compared with the control sows ($P > 0.10$; Table 2). Sow parity affected BW at day 109 with P0 sows having greater BW over parity P3+ ($P = 0.046$) and P6+ ($P = 0.002$) sows but not different from P1+ sows ($P = 0.452$). Consequently, gilts had greater BW gain during gestation than P3+ ($P = 0.050$) and P6+ ($P = 0.020$) sows but similar to P1+ sows ($P = 0.694$; Table 2). Conversely, gilts lost the greatest weight during lactation followed by P1+, P3+, and P6+ ($P = 0.001$). From day 30 to wean, BW gain was greatest for parity P6+ compared with P0 ($P = 0.001$), P1+ ($P = 0.001$) but similar to P3+ ($P = 0.278$) sows. Sows fed 2× daily had tendency to gain BF from days 30 to 109 of gestation ($P = 0.053$) but tended to lose BF during lactation ($P = 0.091$) relative to the control sows. Feeding sows 3× daily resulted in similar BF gains during gestation compared with sows fed 2× ($P = 0.288$) and control group ($P = 0.697$). Lactation BF lost tended to be greater with sows fed 3× daily ($P = 0.077$) and 2× daily ($P = 0.091$) relative to sows on single feeding regime. Sows on 2× feeding schedule had similar lactation BF lost compared with sows fed 3× daily ($P = 0.124$). Sow parity did not affect gestation and lactation BF gain ($P > 0.10$). From day 30 to wean, gilts lost more BF compared with P3+ ($P = 0.003$) and P6+ ($P = 0.003$) sows but had tendency to lose BF relative to P1+ ($P = 0.094$). Parity P1+, P3+, and P6+ sow had similar BF gain from day 30 to wean ($P > 0.10$).

Effects of Feeding Frequency and Parity on Sow and Reproductive Performance under Isocaloric Condition per Kilogram Live BW^{0.75}

Feeding frequency did not affect ($P > 0.10$) gestation ADG, sow lactation ADFI, lactation length, and wean-to-estrus interval relative to the conventional feeding regime (Table 3). Sows fed 3× daily

during gestation had improved lactation feed efficiency compared with sows fed 2× daily ($P = 0.040$) but similar to sows fed 1× daily ($P = 0.338$). Compared with the conventional feeding regime, feeding sows 2× ($P = 0.056$) or 3× daily ($P = 0.098$) tended to have larger litter size at weaning. Sows fed 2× daily had lower number of stillborn relative to the control sows ($P = 0.035$) but similar to sows fed 3× daily ($P = 0.180$). Sows fed 2× and 3× daily had similar number of stillborn ($P = 0.782$) and piglets weaned ($P = 0.997$). Feeding frequency did not change ($P > 0.10$) total number of piglets born, live piglet born, mummified fetuses, average piglet birth weight, 72 h mortality, preweaning mortality, number of piglets with low viability, average weaning weight, piglet ADG, and adjusted litter weight gain. Parity P6+ ($P = 0.007$) and P3+ ($P = 0.005$) had greater number of stillborn than P1+ sows.

Younger sows (group P0) had lower lactation ADFI than sows of P1+, P3+, and P6+ ($P = 0.001$; Table 3). Sow parities P1+ ($P = 0.031$) and P3+ ($P = 0.014$) had improved lactation feed efficiency than parity group P0 sows but did not differ from P6+ sows ($P = 0.122$ and $P = 0.954$), respectively. Wean-to-estrus interval was not different among sow parities ($P > 0.10$) or treatment ($P > 0.10$). Older sows (P6+) had shorter ($P = 0.033$) lactation length relative to parity P3+ sows. When parity increased from parity 0 to 5, there were increases in total piglets born and piglet born alive, but these parameters declined after parity 5 ($P < 0.05$). Compared with P3+ ($P = 0.027$ and $P = 0.028$) and P6+ ($P = 0.008$ and $P = 0.038$), P1+ sows had greater piglet birth weight and reduced number of low viable piglets, respectively. No difference in number of mummified piglets was detected among sow parity ($P > 0.10$). Parity P6+ sows had higher percentage of 72 h piglet mortality compared with P1+, P3+, and P0 sows ($P < 0.05$). Similarly, preweaning piglet mortality was greater in parity P6+ relative to P0, P1+, and P3+ sows ($P < 0.05$).

DISCUSSION

Feeding frequency results in pregnant sows has been contradictory in experiments (Williams et al., 1979; Michel et al., 1980; Wittman, 1986; Holt et al., 2006; Schneider et al., 2007). The discrepancies could be partly due to differences in methods of equalizing energy intake between different feeding regimes in the experiments. For the first time we fed nulliparous and multiparous sows at 125% of their maintenance requirement as recommended

Table 2. Main effects of feeding frequency and parity on sow's performance during gestation and lactation under isocaloric intake (least squares means)¹

Item	Feeding frequency ²					Parity ²		
	T1 (1×)	T2 (2×)	T3 (3×)	P0 ³	P1+ ⁴	P3+ ⁵	P6+ ⁶	
Sow number	58	61	58	25	46	54	52	
Sow BW, kg								
Initial day 30	207.79 ± 4.26 ^c	211.49 ± 3.36	211.09 ± 4.17	200.46 ± 5.29	206.45 ± 4.50	214.14 ± 4.23	219.44 ± 4.28	
At day 109	245.15 ± 4.23	250.73 ± 4.11	248.59 ± 4.16	246.00 ± 5.67 ^a	244.35 ± 4.58 ^{ab}	249.49 ± 4.17 ^b	252.78 ± 4.25 ^b	
Farrowing ⁷	221.48 ± 5.24	228.32 ± 5.14	224.86 ± 5.19	221.00 ± 5.19	220.84 ± 5.53	224.51 ± 5.19	233.21 ± 5.25	
Wean	226.96 ± 4.06	231.65 ± 3.97	228.72 ± 4.03	206.73 ± 5.18	221.97 ± 4.37	237.74 ± 4.02	250.05 ± 4.07	
Sow BW change, kg								
Day 30 to 109	37.95 ± 4.02	40.15 ± 4.00	37.39 ± 4.00	44.83 ± 4.32 ^a	39.71 ± 4.09 ^{ab}	35.69 ± 4.01 ^{bc}	33.76 ± 4.03 ^c	
Lactation	6.74 ± 3.64	4.51 ± 3.61	4.83 ± 3.63	-14.27 ± 4.16 ^a	1.83 ± 3.74 ^b	13.21 ± 3.58 ^c	16.34 ± 3.60 ^d	
Day 30 to wean	19.53 ± 4.80	20.62 ± 4.78	18.01 ± 4.78	8.87 ± 5.29 ^a	16.74 ± 4.87 ^b	23.18 ± 4.79 ^c	28.85 ± 4.81 ^d	
Sow BF, mm								
Initial day 30	14.72 ± 0.62	14.28 ± 0.60	14.03 ± 0.61	18.60 ± 0.82	14.01 ± 0.67	12.54 ± 0.61	12.21 ± 0.62	
At day 109	16.91 ± 0.81	17.83 ± 0.79	17.25 ± 0.80	22.05 ± 1.09	17.42 ± 0.88	15.58 ± 0.80	14.28 ± 0.81	
Farrowing	14.68 ± 1.82	16.59 ± 1.74	15.16 ± 1.75	18.98 ± 1.98	14.90 ± 1.83	14.89 ± 1.85	13.12 ± 1.77	
Weaning	14.61 ± 0.70	15.17 ± 0.68	14.53 ± 0.69	17.63 ± 0.92	14.27 ± 0.76	13.76 ± 0.69	13.42 ± 0.70	
Sow BF change, mm								
Day 30 to 109	2.19 ± 0.64	3.56 ± 0.63	3.21 ± 0.54	3.37 ± 0.80	3.49 ± 0.68	3.06 ± 0.64	2.03 ± 0.65	
Lactation	-0.24 ± 0.65	-0.85 ± 0.62	-0.88 ± 0.63	-1.62 ± 0.69	-0.97 ± 0.65	-1.23 ± 0.65	0.20 ± 0.63	
Day 30 to wean	-0.12 ± 0.60	0.87 ± 0.59	0.52 ± 0.59	-1.13 ± 0.72 ^a	0.41 ± 0.63 ^b	1.24 ± 0.60 ^b	1.17 ± 0.60 ^b	

¹BW and BF at day 30 was used as covariate for BW and BF evaluations at day 109, 24 h postpartum, and at weaning.²Least square means ± SE.³Parity group 0 = pregnant gilts that had not produced a litter.⁴Parity group P1+ = first and second parity sows.⁵Parity group P3+ = third to fifth parity sows.⁶Parity group P6+ = sixth to ninth parity sows.⁷No apparent two-way significant interaction was noticed for any of the variables tested.^{a-c}Means within a row of treatment with different subscript letter were significantly different $P < 0.05$.^{a-c}Means within a row of parity with different subscript letter were significantly different $P < 0.05$.

Table 3. Main effects of feeding frequency and parity on sow's reproductive performance during lactation (least squares means)¹

Item	Feeding frequency			Parity			
	T1 (1×)	T2 (2×)	T3 (3×)	P0 ²	P1+ ³	P3+ ⁴	P6+ ⁵
Number of sows	58	61	58	25	46	54	52
Lactation length, d	19.70 ± 0.25 ⁶	19.69 ± 0.24	19.82 ± 0.25	19.44 ± 0.33 ^{ab}	19.83 ± 0.27 ^{ab}	20.27 ± 0.25 ^a	19.41 ± 0.25 ^b
ADFI (day 1 to 19), kg	5.40 ± 0.24	5.55 ± 0.23	5.41 ± 0.24	3.94 ± 0.29 ^a	5.64 ± 0.25 ^b	6.01 ± 0.24 ^b	6.23 ± 0.24 ^b
ADG (day 30 to 109), kg	0.474 ± 0.05	0.497 ± 0.05	0.473 ± 0.05	0.568 ± 0.06 ^a	0.487 ± 0.05 ^{ab}	0.453 ± 0.05 ^b	0.417 ± 0.05 ^b
Wean-to-estrus interval, d	5.49 ± 0.30	5.57 ± 0.29	5.46 ± 0.30	5.67 ± 0.30	5.40 ± 0.30	5.41 ± 0.30	5.54 ± 0.30
Sow lactation G:F ⁷	0.472 ± 0.04 ^{ab}	0.451 ± 0.04 ^a	0.504 ± 0.04 ^b	0.421 ± 0.04 ^a	0.501 ± 0.04 ^b	0.506 ± 0.04 ^b	0.474 ± 0.04 ^{ab}
Litter performance ⁸							
Total pigs born	14.70 ± 0.51	14.99 ± 0.50	14.77 ± 0.50	14.79 ± 0.71 ^{ab}	15.30 ± 0.57 ^a	15.97 ± 0.51 ^a	13.23 ± 0.51 ^b
No. of born alive	12.10 ± 0.26	12.90 ± 0.19	12.49 ± 0.20	12.83 ± 0.26	13.14 ± 0.22	13.35 ± 0.21	10.68 ± 0.21
No. of mummified piglets	0.27 ± 0.08	0.36 ± 0.10	0.51 ± 0.10	0.17 ± 0.09	0.58 ± 0.12	0.42 ± 0.09	0.42 ± 0.10
No. of stillborn	2.29 ± 0.20 ^b	1.67 ± 0.17 ^a	1.81 ± 0.19 ^{ab}	1.74 ± 0.25 ^{ab}	1.56 ± 0.19 ^a	2.19 ± 0.20 ^b	2.19 ± 0.20 ^b
Average birth weight, kg	1.39 ± 0.04	1.38 ± 0.04	1.40 ± 0.04	1.40 ± 0.05 ^{ab}	1.47 ± 0.04 ^a	1.35 ± 0.04 ^b	1.33 ± 0.04 ^b
Litter size after cross-fostering ⁹	12.48 ± 0.31	12.99 ± 0.30	12.58 ± 0.31	12.44 ± 0.41 ^a	12.83 ± 0.34 ^a	13.38 ± 0.31 ^a	12.08 ± 0.31 ^b
72 h mortality, %	4.59 ± 1.25	5.13 ± 1.22	4.99 ± 1.24	3.85 ± 1.60 ^a	3.59 ± 1.34 ^a	4.12 ± 1.26 ^a	8.06 ± 1.27 ^b
Prewaning mortality, %	7.75 ± 1.14	7.05 ± 1.11	5.67 ± 1.12	4.56 ± 1.56 ^a	5.22 ± 1.25 ^a	6.83 ± 1.15 ^a	10.69 ± 1.17 ^b
Low viability piglets ¹⁰	1.03 ± 0.17	1.06 ± 0.17	0.92 ± 0.17	0.81 ± 0.23 ^{ab}	0.61 ± 0.19 ^a	1.30 ± 0.17 ^b	1.27 ± 0.17 ^b
Pigs weaned per litter, day 18	10.48 ± 0.18	10.88 ± 0.17	11.01 ± 0.18	11.12 ± 0.24 ^a	11.49 ± 0.20 ^a	10.92 ± 0.19 ^a	9.63 ± 0.19 ^b
Av. weaning weight, kg	5.96 ± 0.11	5.93 ± 0.10	6.02 ± 0.11	5.69 ± 0.14 ^a	6.29 ± 0.12 ^b	6.00 ± 0.11 ^{ab}	5.89 ± 0.11 ^a
Adjusted litter weight gained	45.44 ± 1.15	47.64 ± 1.09	48.63 ± 1.12	46.59 ± 1.59 ^a	53.61 ± 1.26 ^b	48.71 ± 1.16 ^a	40.03 ± 1.15 ^c
Piglet ADG, kg	0.232 ± 0.01	0.231 ± 0.01	0.234 ± 0.01	0.218 ± 0.01 ^a	0.245 ± 0.01 ^b	0.235 ± 0.01 ^a	0.232 ± 0.01 ^a

¹Lactation length was used as covariate for ADFI, piglet ADG, average weaning weight, and adjusted litter weight gain.²Parity group 0 = pregnant gilts that had not produced a litter.³Parity group P1+ = first and second parity sows.⁴Parity group P3+ = third to fifth parity sows.⁵Parity group P6+ = sixth to ninth parity sows.⁶Least square means ± SE.⁷Sow lactation G:F was calculated as summation of sow BW loss (or gain) and litter weight gain relative to feed disappearance.⁸No apparent two-way significant interaction was noticed except for sow lactation G:F.⁹Litter size after cross-fostering was used as covariate for number of piglets weaned.¹⁰Low viable piglets are weak piglets with no suckling reflex, lack vitality, and have no possibility of survival.^{a-b}Means within a row of treatment with different subscript letter were significantly different $P < 0.05$.^{a-c}Means within a row of parity with different subscript letter were significantly different $P < 0.05$.

by [NRC \(2012\)](#) to arrive at feed restriction levels similar to their normal gestation energy intake to throw more light on effects of feeding frequency and parity on sow performance. It is common to restrict breeding dams to 10% to 65% of their ad libitum feed intake which is above, below, or equal to energy requirements for maintenance. Such level of feed restriction results in retarded growth in pre-pubertal, mature, and early pregnant gilts ([Prunier and Quesnel, 2000](#)), suppressed growth ([Booth et al., 1996](#)), or enhanced growth ([Amdi et al., 2013](#)). In the current study, feeding nulliparous and multiparous pregnant pigs 25% above their maintenance requirements from day 30 of gestation increased body weight of breeding dams throughout gestation, suggesting that their requirement for energy was not compromised.

Effects of Feeding Frequency under Isocaloric Intake per Live BW^{0.75} on Sow Performance

Under isocaloric conditions per kilogram live BW^{0.75}, meal frequency did not influence sow BW changes either during gestation or lactation. This result resonates with the findings of other researchers under pair feeding regime ([Romsos et al., 1978](#); [Schneider et al., 2007](#)) but contradicts the results of [Holt et al. \(2006\)](#). [Holt et al. \(2006\)](#) reported that sows fed 2× daily during gestation consistently gained BW in gestation and throughout lactation relative to sows fed 1× daily. The difference in results is attributable to differences in feeding levels. While sows in the current study received similar energy per kilogram live BW^{0.75}, [Holt and others](#) fed their sows to a target BCS of 3 and some sows received additional feed when desirable. Our results and others ([Romsos et al., 1978](#); [Schneider et al., 2007](#)) suggest that an alteration in meal frequency does not influence BW, provided the sows are pair-fed or fed based on kilogram live BW^{0.75}.

Sow fed 2× daily tended to have increased BF thickness during gestation compared to the control sows but this observation was not evident in sows fed 3× daily. Our initial assumption was that under isocaloric conditions, consumption of multiples meals within the day could be a metabolic advantage. Our data suggest that under limit-fed regime, the threshold of 2× daily feeding is more desirable than 3× daily feeding regime. At the whole animal level, [Sharma et al. \(1973\)](#) reported that pigs fed thrice daily had greater maintenance requirements, greater energy needs for digestion due to the thermic effect of feed, and increase in activity and energy expenditure. Similarly, rats ([Leveille and O'Hea, 1967](#)) and pigs ([Friend and Cunningham,](#)

[1964](#)) fed 2× or 1× daily were generally less sensitive to the excitation associated with the distribution of feed than animals receiving multiple small meals. Also, [LeBlanc and Diamond \(1986\)](#) reported that diet-induced thermogenesis was doubled in dogs that were fed 4 small meals compared to single meal of isocaloric diet. Therefore, it could be speculated that nulliparous and multiparous sows fed 2× in our study had lower energy expenditure than the group fed 3× daily and this probably explains the greater BF in sows fed 2× vs. 3×.

However, the greater gestational BF gain of sows fed 2× daily relative to sows fed 1× daily is puzzling since they received the same amount of dietary energy per kilogram BW^{0.75}. It is documented that given similar quantity of feed, sows fed 2× daily spent more time feeding than similar group of sows receiving their daily ration 1× ([Holt et al., 2006](#)) while heat production (HP) per minute of standing activity was 14.9 kJ in sows ([Noblet et al., 1993](#)). We therefore expected sows fed 2× daily to have increased activity, greater maintenance energy requirement, and reduced BF compared to sows fed 1× daily. We theorized that sows fed 2× daily utilize dietary energy more efficiently than sows fed 1× daily. Therefore, we speculate that the marginal energy derived from 2× feeding is far more than is needed to compensate for the marginal energy required for increased activity and feeding. [Botermans et al. \(2000\)](#) noticed a greater output of enzymes from the exocrine pancreas when pigs were fed 12 small meals in comparison with 1 large meal per day. However, it was reported that energy digestibility of diets was not influenced by feeding frequency in sows ([Holt et al., 2006](#)) and with young pigs ([Sharma et al., 1973](#)). The proper explanation for this disparity in sow BF gain requires further investigation. Although feeding frequency did not influence BW changes in sows, it tended to affect BF thickness. Therefore, BW change alone, without assessing BF change, can be misleading when evaluating sows during gestation and lactation.

The number of pigs weaned per sow per year (PWSY) is a short-term good measurement of sow herd productivity ([Koketsu et al., 2017](#)). One of the significant findings in the current study was that sows fed 2× and 3× daily during gestation tended to wean 0.40 and 0.53 more piglets, respectively, than sows on the conventional feeding regime. Previously, [Holt et al. \(2006\)](#) and [Williams et al. \(1979\)](#) reported that feeding frequency had no effect on any litter performance traits. A plausible explanation for differences in results is the method of feeding between experiments. In an attempt to standardize

our experimental conditions in terms of ME intake, we fed our sows based on their live BW^{0.75} and adjusted the feed with advancing of pregnancy. On the other hand, Holt et al. (2006) fed 1.88 kg of feed and increased the feed at day 40 and 80 of gestation if sow BCS was below 3. Although Holt et al. (2006) feeding regime resulted in a 0.5 mm gain in BF from day 40 to 109 of gestation, our feeding regime resulted in 3.38 mm gain in BF thickness from day 30 to 109 of gestation. We speculate that higher BF gains in our study provided additional energy reserves that was mobilized to support colostrum and milk synthesis enabling piglet survival and improved the number of piglets weaned since sows in good condition produce milk with a higher fat and energy content relative to thin sows (O'Grady et al., 1973; Klaver et al., 1981; Amdi et al., 2013). Additionally, the amount of body fat reserves stored during gestation partly determines the performance during lactation (Amdi et al., 2013).

Feeding frequency elicited a response on the number of stillborn. Sows fed 2× daily had lower number of stillborn compared to sows fed 1× daily during gestation. Pigs utilize glucose as the main energetic substrate for fetal growth and the rate of glucose utilization decreases in sows during late pregnancy to spare glucose for the gravid uterus utilization (Raguvaran et al., 2017); which also occurs in pregnant rat (Leturque et al., 1984). Physiological reduction in maternal glucose tolerance during late gestation resulted in higher number of stillborn piglets (Schaefer et al., 1991). We speculate that increasing meal frequency during gestation enhanced glucose tolerance of pregnant sows by spreading the nutrients load during the day to reduce the number of stillborn at farrowing.

Effects of Sow Parity under Isocaloric Intake per Live BW^{0.75} on Sow Performance

With respect to parity, BW gain and ADG during gestation was greater in gilts than older sows. Kraeling and Webel (2015) explained that while mature sows have decreased growth rate, gilts are still growing and therefore have a higher growth rate. Furthermore, maintenance during late gestation represents approximately 80% and 60% of energy requirement for sows and gilts, respectively (NRC, 2012). Hence, sows preferentially partition more energy toward maintenance than gilt while gilts partition more energy toward growth than sows (Gonçalves et al., 2016). Hence, parity of sow BW gain during gestation followed a pattern with younger sows gaining more than older sows.

Parity category P0, P1+, P3+, and P6+ gained 44.83, 39.71, 35.69, 33.76 kg, respectively, during gestation.

In this study, gilts' feed intake during lactation was lower than other sow parities. This resonates with a body of scientific literature (Gonçalves et al., 2016; Pouloupoulou et al., 2018). Lower lactation feed intake of primiparous sows was attributable to lower feed intake capacity which led to significant BW losses in lactation. The amplitude and the nature of the nutritional deficit are determinants of the degree of body reserve mobilization (Quesnel et al., 2005). It was reported that BW loss greater than 12% during lactation extends the weaning-to-service interval in primiparous sows (Eissen et al., 2003; Thaker and Bilkei, 2005). Lactation weight loss of 6.1% in our primiparous sows did not prolong the wean-to-service interval relative to older parity category sows. Wean-to-service intervals appeared to be minimized at lactation weight losses of about 5% (Thaker and Bilkei, 2005).

Both 72 h and preweaning piglet's mortality was greater in older sows (P6+) than younger parity sows and gilts. The finding is consistent with data presented by Gonçalves et al. (2016). The number and positioning of functional teats are both important for suckling piglets. Piglets are inclined to suckle first from teats that are close to the abdominal midline with longer inter-teat distances (Balzani et al., 2016). With younger parity sows, proximity to the midline renders teats more accessible. However, with older parities sows, larger udders may make teat access for piglets more difficult (Vasdal and Andersen, 2012; Alexopoulos et al., 2018). In addition, older sows are more susceptible to lameness (Li and Gonyou, 2013) and increase the possibility of piglet crushing which will culminate in higher mortality rates (Pluym et al., 2013). The magnitude of this impact on production was observed at weaning where older sows wean fewer piglets than younger parity sows even though litter size was equalized 24 h postpartum through cross-fostering. Cross-fostering is widely adopted swine industry practice to reduce the risk of high piglet mortality when piglet numbers exceed available functional teats or sow's rearing capacity (Baxter et al., 2013). To improve production efficiency, our data suggest that cross-fostering to balance the number of piglets nursed by a sow may work with younger parities but not older or advanced parities or litter standardization practiced instead of litter size equalization as fostering strategy.

Parity groups 3+ and 6+ sows produced higher number of stillborn. The occurrence of stillbirth is

usually greatest in high parity sows, which could be attributed to poor uterine muscle tone, longer farrowing duration, and dystocia caused by fatness (Kirkden et al., 2013). In addition, Maes et al. (2004) reported a significant association between low BF at the end of gestation with a high incidence of stillborn piglets. They reported that sows with 14 to 15.5 mm BF or more had a lower percentage of stillborn piglets. Our data suggest that sows with 17.1 mm BF or more had reduced number of stillborn piglets at the end of gestation which was observed in parity categories 0 and 1+ sows.

CONCLUSION

Under isocaloric intake per kilogram live metabolic weight, feeding frequency had no effect on pregnant sows' BW changes during gestation, lactation feed intake, litter characteristics at farrowing, piglet' BW and gain at the end of the suckling period. Feeding gestation sows 2× daily tended to increase BF depth during gestation and reduced the number of stillborn compared with control sows. Sows fed 2× and 3× daily during gestation exhibited a potential to improve the number of piglets weaned compared with sows on once a day feeding regime. Under isocaloric conditions per live BW^{0.75}, sow parity did not affect gestation BF change although gilts had greatest BW gain. Parity (P6+) sows had greatest BW gain during lactation but greater number of stillborn, 72 h, and preweaning mortalities relative to younger sows.

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