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Effects of dietary energy levels on physiological parameters and reproductive performance of gestating sows over three consecutive parities

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Objective: This experiment was to evaluate the effects of the dietary energy levels on the physiological parameters and reproductive performance during gestation over three parities in sows.
Methods: A total of 52 F1 gilts (Yorkshire×Landrace) were allotted to one of four dietary treatments using a completely randomized design. The treatments contained 3,100, 3,200, 3,300, or 3,400 kcal of metabolizable energy (ME)/kg diet but feed was provided at 2.0, 2.2, and 2.4 kg/d in the first, second and third parity, respectively.
Results: The body weight and body weight gain during gestation increased as the dietary energy level increased ($p<0.05$, and $p<0.01$) in the first parity. In the second parity, the body weight of sows was the lowest ($p<0.05$) when 3,100 kcal of ME/kg treatment diet was provided. The body weight was higher as the dietary energy level increased ($p<0.05$) during the gestation period in the third parity. During lactation, the voluntary feed intake of lactating sows tended to decrease when gilts were fed higher energy treatment diet ($p = 0.08$) and the body weight, body weight gain were increased by dietary energy level during gestation ($p< 0.05$). Backfat thickness was not affected by dietary treatment during the gestation period in three parities, interestingly backfat change from breeding to d 110 of gestation was higher as the dietary energy level increased at the first parity ($p<0.05$). When gilts were fed 3,400 kcal of ME/kg treatment diet a higher number of weaning piglets was observed in the first parity ($p<0.05$). The highest culling rate (69%) was seen when gestating sows were fed 3,100 kcal/kg ME treatment diet during three parities.
Conclusion: In conclusion, the adequate energy intake of gestating sows should be 6,400 or 6,600 kcal of ME/d, 7,040 or 7,260 kcal of ME/d, and 7,680 or 7,920 kcal of ME/d for parity 1, 2, and 3, respectively.

Keywords: Body Weight; Bakfat Thickness; Energy Level; Reproductive Performance; Sow

INTRODUCTION

Gestation diets for gilts and sows are of central importance to the swine industry because of their importance to reproductive productivity and longevity of the animal. Jang et al [1] also indicated that the energy intake during gestation should be limited to control body weight gain and maintain an appropriate body condition, especially, in sows from the first to third parity, as adequate energy consumption is required during gestation for the maintenance of body maturation, the growth of the fetus and body preservation. With the development of the genetic potential, many studies were performed to evaluate the nutrient requirement for modern sows. Long et al [2] stated that the provision of high energy feed during gestation caused increased body weight and a backfat thickness loss during lactation. Also, the model developed by NRC [3] suggested that the energy requirement of the gestating gilt and sow should be between 6,678 and 8,182 kcal of metabolizable energy (ME)/d. However, data on the development of the energy level during gestation and its effect on successive parities of gestating sows are lacking. Therefore, the objective of the study was to evaluate the optimum dietary energy level that produced the best physiological parameters and reproductive performance in high-producing modern sows over three consecutive parities.

MATERIALS AND METHODS

The protocol for the present experiment was approved by the Seoul National University Institutional Animal Care and Use Committee (SNUIACUC; SNU-160819-9) in Republic of Korea.

Animal

A total of 52 gilts (Yorkshire×Landrace) weighing approximately 85 kg were selected and housed in an 11×14 m barn. The sows were provided feed and water *ad libitum* until 120 kg of body weight was reached and were then moved to an individual gestation stall cage with a concrete slatted floors (0.64× 2.40 m). The sows were fed 800 g of an individual diet, twice daily for an average daily gain of 750 g/d. Gilts were mated at an average body weight of 135.82±0.85 kg after three or four estrus cycles. Estrus was diagnosed twice daily in the presence of a mature boar, using the backfat pressure test. Gilts and weaning sows were artificially inseminated with fresh diluted semen (Darby A.I. center, Chungju, Korea) twice at a 12 h interval. A total of 52 crossbred gilts (Yorkshire×Landrace) with 135.82±0.85 kg body weight (BW) were allotted to 4 dietary treatments by BW and backfat thickness in a completely randomized design with 13 replicates. Pregnancy of gilts and sows were diagnosed by an ultrasound analyzer (Easyscan, Dongjin BLS Co., Ltd., Gwangju, Gyeonggi, Korea) on days 30 and 60 after mating.

Experimental design and animal management

Experimental diets and treatment of sows were not changed in the whole experiment period. Experimental diets for gestating gilts and sows were formulated to contain 13.08% crude protein (CP), 0.86% lysine, 0.90% calcium, and 0.70% phosphorus, with an energy content of 3,100, 3,200, 3,300, or 3,400 kcal of ME/kg and diets were provided daily at 2.0 kg/d for the 1st parity, 2.2 kg/d for the 2nd parity, 2.4 kg/d for the 3rd parity and 3 kg from weaning to estrus. Lactation diets contained 3,265 kcal ME/kg, 17.07% CP, 1.26% lysine, 0.90% calcium, and 0.70% phosphorus (Table 1). All other nutrients were formulated to meet or exceed the NRC requirements [3]. Gilts and sows were housed in temperature-controlled rooms and placed in an individual crate (2.4× 0.65 m^2) with a concrete floor until 110 d of gestation. After 110 d of gestation, pregnant gilts and sows were washed and moved into farrowing crates (2.4×1.8 m^2). During lactation, all sows were fed the same commercial lactation diet. After farrowing, the lactation diet was increased gradually from 1.0 kg/d until 5 d postpartum and then provided *ad libitum* during lactation. Weaning was at approximately 21 d and sows returned to stall cage again for the next reproductive cycle. Gilts and sows were excluded from the feeding trial for reproductive problems and lameness.

Measurements and analysis

The BW and backfat thickness at the P_2 position of the sows were measured. Blood samples were collected at breeding, 110 days of gestation, 24 h post-farrowing and 21 days of lactation from sows. The number of total piglets born, piglets born alive, still born, and mummified fetuses as well as the piglet BW were recorded. The fat and protein mass of primiparous and multiparous sows were calculated using the equations of Dourmad et al [4].

$$\text{EBW (kg)} = \text{empty body weight } (= 0.905\times BW^{1.013})$$

$$\text{Fat (kg)} = -26.4+0.221\times(\text{EBW, kg})+1.331\times(\text{Backfat, mm})$$

$$\text{Protein (kg)} = 2.28+0.178\times(\text{EBW, kg})+0.333\times(\text{Backfat, mm})$$

Table 1. Formula and chemical composition of gestation and lactation diets (as dry matter basis)

Criteria	Energy level in gestation				Lactation
	ME 3,100 kcal/kg	ME 3,200 kcal/kg	ME 3,300 kcal/kg	ME 3,400 kcal/kg	
Ingredients (%)					
Corn	56.59	54.56	52.53	50.50	67.51
Soybean meal (46% CP)	10.09	10.44	10.78	11.12	25.57
Tallow	0.45	2.13	3.82	5.50	-
Soy oil	-	-	-	-	1.30
Barley	25.00	25.00	25.00	25.00	-
Rapeseed meal	3.60	3.60	3.60	3.60	-
L-lysine-HCl	0.41	0.40	0.40	0.40	0.60
DL-methionine	0.04	0.04	0.04	0.04	-
Dicalcium phosphate	2.36	2.39	2.41	2.43	2.30
Limestone	0.86	0.84	0.82	0.81	0.85
Vit. mix[1)]	0.10	0.10	0.10	0.10	0.20
Min. mix[2)]	0.10	0.10	0.10	0.10	0.10
Salt	0.25	0.25	0.25	0.25	0.42
Choline chloride-50	0.15	0.15	0.15	0.15	0.15
Chemical compositions[3)] (%)					
ME (kcal/kg)	3,100	3,200	3,300	3,400	3,265
CP	13.08	13.08	13.08	13.08	17.07
Lys	0.86	0.86	0.86	0.86	1.26
Met	0.23	0.23	0.23	0.23	0.25
Ca	0.90	0.90	0.90	0.90	0.90
Total P	0.70	0.70	0.70	0.70	0.70

ME, metabolizable energy; CP, crude protein.

1) Provided per kg of diet: Vit A, 10,000 IU; Vit D_3, 1,500 IU; Vit E, 35 IU; Vit K_3, 3 mg; Vit B_2, 4 mg; Vit B_6, 3 mg; Vit B_{12}, 15 μg; pantothenic acid, 10 mg; biotin, 50 μg; niacin, 20 mg; folic acid 500 μg.

2) Provided per kg of diet: Fe, 75 mg; Mn, 20 mg; Zn, 30 mg; Cu, 55 mg; Se 100 μg; I, 250 μg; Co, 250 μg.

3) Calculated value.

Blood samples were collected from the jugular vein of sows with tubes (serum and EDTA tube, BD Vacutainer, Berkshire, UK) and centrifuged immediately at 3,000 rpm at 4°C, and then, samples were stored at –20°C until later analysis. Colostrum and milk were collected from the first and second teats at 24 h and 21 d postpartum after an intravascular injection of 5 IU oxytocin (Komi oxytocin inj. Komipharm International Co., Ltd., Siheung, Korea) in the ear. All samples were stored at –20°C until analysis. A proximate analysis of colostrum and milk samples was conducted using a Milkoscan FT 120 (FOSS Electric, Sungnam, Korea). The glucose and blood urea nitrogen (BUN) concentrations were analyzed using a kinetic UV assay (Glucose Hexokinase Kit; UREA/BUN Kit, Roche, Mannheim, Germany). Plasma free fatty acid (FFA) concentrations were determined according to the colorimetric Acyl-CoA synthetase Acyl-CoA oxidase method [5] using a commercial kit (Wako FFA c Kit; Wako chemical, Osaka, Japan). The fatty acid content in colostrum was analyzed on an Agilent 7890 gas liquid chromatograph (Agilent Technologies, Palo Alto, CA, USA) equipped with a flame ionization detector and an SP-2560 (i.d. 100 m×0.25 mm×0.20 μm) film column. Nitrogen was used as carrier gas, injector core temperature was 250°C, detector temperature was 260°C and column temperature was programmed to begin at 170°C and then increase to 250°C and remain at 240°C for 40 min. Chromatography was calibrated with a mixture of 37 different fatty acids (FAME 37; Supelco Inc., Bellefonte, PA, USA) and this standard containing fatty acids ranging from C4:0 to C24:1n9 and samples were added 250 μL of internal standard spike solution (Pentadecanoic acid; Sigma-Aldrich, Darmstadt, Germany) by the method of AOAC [6].

Statistical analysis

Data were analyzed by analysis of variance with a completely randomized design using the general linear model procedure implemented in SAS. The least squares means were calculated for each independent variable. Orthogonal polynomial contrasts were used to determine the linear and quadratic effects by increasing the dietary energy level during gestation for all measurements of sows and piglets. The individual sows and their litters were used as the experimental unit. The alpha level used for the determination of significance for all analyses was 0.05 and for the determination of trends was $p>0.05$ and $p<0.10$

Table 2. Effects of dietary energy level on the body weight of gestating and lactating sows over three consecutive parities

Criteria	Treatment				SEM	p-value	
	3,100[1)]	3,200	3,300	3,400		Linear	Quadratic
Gestation (kg)							
Breeding[2)]							
Parity 1	136.00	135.95	135.68	135.35	0.85	0.64	0.96
Parity 2	155.81	163.17	157.33	156.79	1.47	0.72	0.21
Parity 3	169.90	179.63	178.63	181.69	2.29	0.16	0.53
d 110							
Parity 1	178.50	182.18	182.59	185.81	1.42	0.04	0.74
Parity 2	208.57	220.44	219.13	214.13	1.66	0.28	0.01
Parity 3	220.75	234.25	240.63	236.88	3.01	0.04	0.12
Total body weight gain (Breeding to d 110, kg)							
Parity 1	42.50	46.22	46.91	50.46	1.08	0.01	0.69
Parity 2	51.21	56.39	61.79	57.33	1.52	0.07	0.12
Parity 3	50.85	54.63	62.00	55.19	1.70	0.16	0.10
Lactation (kg)							
Farrowing[3)]							
Parity 1	164.72	165.68	162.08	169.00	1.28	0.53	0.26
Parity 2	188.29	197.39	193.08	193.45	2.02	0.46	0.18
Parity 3	199.63	219.44	220.00	221.14	3.23	0.03	0.29
Weaning							
Parity 1	174.11	173.45	168.88	167.27	1.55	0.03	0.70
Parity 2	177.00	193.78	182.38	183.15	2.44	0.59	0.06
Parity 3	206.86	221.13	222.14	221.71	3.31	0.24	0.53
Total body weight gain (Farrowing to weaning, kg)							
Parity 1	9.39	7.77	6.79	–1.73	1.24	0.01	0.10
Parity 2	–11.29	–3.61	–10.71	–10.30	1.34	0.82	0.25
Parity 3	7.25	1.69	2.14	0.57	1.67	0.25	0.70
Overall body weight gain (Breeding to weaning, kg)							
Parity 1	39.72	37.50	33.79	31.92	1.31	0.06	0.90
Parity 2	19.64	29.72	25.04	24.39	1.56	0.87	0.26
Parity 3	37.13	41.50	43.71	41.07	1.79	0.59	0.54

SEM, standard error of the means; ME, metabolizable energy.
1) Energy intake ME kcal/kg. 2) Breeding day. 3) 24 hours postfarrowing.

RESULTS

The BW and body weight gain during gestation increased as the dietary energy level increased (linear, p<0.05, and p<0.01, respectively, Table 2) in the first parity. In the second parity, BW was the lowest (quadratic, p<0.05) in the 3,100 kcal/kg ME treatment with a higher body weight gain (linear, p = 0.07, Table 2). The BW increased with an increasing energy level (linear, p<0.05) during gestation in the third parity (Table 2). During lactation, an increasing energy level led to lower BW, body weight gain and overall body weight gain (linear, p<0.05, p = 0.06, respectively) in the first parity (Table 2).

Back fat thickness was not affected by the diet during gestation in parity 1, 2, or 3. However, back fat difference from breeding to d 110 of gestation increased linearly (p<0.05) as the dietary energy level increased in parity 1 (Table 3).

The estimated fat and protein masses were calculated based on BW and backfat thickness [5]. The fat mass and protein mass were higher as the energy level increased (linear, p<0.01, and p< 0.05, respectively) during gestation in parity 1 (Table 4). During lactation, the fat mass and protein mass decreased (linear and quadratic, p<0.01, and p<0.05, respectively) with an increased dietary energy level in parity 1 (Table 5).

The voluntary feed intake of sows tended to decrease (linear, p = 0.08) when the dietary energy level increased in parity 1 (Table 6). The weaning to estrus interval (WEI) was not significantly affected by treatment over the three parities (Table 6). The culling rate was the highest in the 3,100 kcal/kg ME treatments.

The 3,400 kcal/kg ME treatment showed the highest number of weaning pigs per litter (quadratic, p<0.05) in the first parity (Table 7).

The BUN concentration in sows tended to be increased by with the dietary energy level at d110 of gestation and 24 h postpartum (linear, p = 0.06, and p = 0.07, respectively) in parity 1 (Figure 1). The glucose concentration was higher (linear, p = 0.07) and tended to be the lowest in 3,300 kcal/kg ME (quadratic, p = 0.06) treatment at 24 h postpartum in parities 1, and 3 (Figure 2). Similarly, the 3,300 kcal/kg ME treatment had a lower glucose concentration at d 110 in the third parity (quadratic, p = 0.06, Figure 2). The FFA concentration was not affected by dietary energy level (Figure 3).

No statistical differences were evident in the fat content of the colostrum and milk (Table 9). The colostrum fatty acids

Table 3. Effects of dietary energy level on the back-fat of gestating and lactating sows over three consecutive parities

Criteria	Treatment				SEM	p-value	
	3,100[1)]	3,200	3,300	3,400		Linear	Quadratic
Gestation (mm)							
Breeding[2)]							
Parity 1	19.32	19.18	18.55	19.08	0.56	0.90	0.55
Parity 2	18.44	18.71	17.58	17.91	0.61	0.81	0.91
Parity 3	17.40	17.00	18.69	19.38	0.69	0.22	0.69
d 110							
Parity 1	20.72	21.27	20.45	23.08	0.70	0.22	0.26
Parity 2	22.50	22.56	21.33	21.92	0.90	0.62	0.82
Parity 3	19.40	19.56	23.13	21.44	0.91	0.32	0.65
Total backfat gain (Breeding to d 110)							
Parity 1	1.40	2.09	1.91	4.00	0.40	0.04	0.32
Parity 2	1.29	3.33	3.75	4.00	0.60	0.38	0.62
Parity 3	2.00	2.56	4.44	2.06	0.54	0.76	0.26
Lactation (mm)							
Farrowing[3)]							
Parity 1	21.06	20.32	20.83	21.77	0.64	0.57	0.49
Parity 2	20.43	21.50	21.25	21.10	0.82	0.83	0.65
Parity 3	20.00	19.56	21.29	23.14	1.01	0.43	0.48
Weaning							
Parity 1	18.94	18.73	19.37	18.27	0.57	0.87	0.77
Parity 2	16.50	18.61	19.00	17.95	0.71	0.59	0.32
Parity 3	18.63	18.00	20.71	20.21	0.90	0.61	0.91
Total backfat gain (Farrowing to weaning)							
Parity 1	−2.12	−1.59	−1.46	−3.50	0.35	0.19	0.08
Parity 2	−3.93	−2.88	−2.25	−3.15	0.60	0.66	0.45
Parity 3	−1.38	−1.56	−0.57	−2.93	0.48	0.55	0.26
Over all backfat gain (Breeding to weaning, mm)							
Parity 1	0.56	−0.45	0.66	−0.81	0.47	0.91	0.72
Parity 2	−3.07	−0.61	1.41	0.67	0.71	0.13	0.36
Parity 3	0.75	1.00	2.21	1.07	0.52	0.71	0.49

SEM, standard error of the means; ME, metabolizable energy.
[1)] Energy intake ME kcal/kg. [2)] Breeding day. [3)] 24 hours postfarrowing.

Table 4. Effects of the dietary energy level on the estimated fat and protein mass of gestating sows over three consecutive parities

Criteria	Treatment				SEM	p-value	
	3,100[1)]	3,200	3,300	3,400		Linear	Quadratic
Estimated fat mass[2)] on gestation (kg)							
Breeding							
Parity 1	26.94	27.98	27.16	27.71	0.82	0.88	0.94
Parity 2	33.03	33.99	30.38	30.71	0.99	0.31	0.92
Parity 3	33.41	34.34	36.08	37.40	1.37	0.49	0.70
d 110							
Parity 1	39.45	40.57	40.71	43.74	1.08	0.09	0.39
Parity 2	45.61	50.39	48.48	48.20	1.36	0.84	0.50
Parity 3	48.14	49.34	55.19	52.74	1.75	0.33	0.82
Gain (Breeding to d 110, kg)							
Parity 1	12.51	12.59	13.56	16.03	0.74	0.03	0.26
Parity 2	12.58	16.40	18.10	17.49	0.90	0.18	0.34
Parity 3	14.73	15.00	19.11	15.34	0.92	0.54	0.35
Estimated protein[3)] mass on gestation (kg)							
Breeding							
Parity 1	31.57	31.90	31.59	31.76	0.40	0.93	0.95
Parity 2	35.69	36.71	35.02	35.04	0.40	0.31	0.58
Parity 3	37.24	38.64	38.93	39.52	0.61	0.36	0.95
d 110							
Parity 1	39.80	40.50	40.54	41.72	0.41	0.04	0.41
Parity 2	44.87	47.46	46.83	46.17	0.48	0.59	0.16
Parity 3	47.06	49.00	51.39	50.10	0.79	0.15	0.46
Gain (Breeding to d 110, kg)							
Parity 1	8.23	8.60	8.95	9.95	0.30	0.01	0.31
Parity 2	9.18	10.75	11.81	11.13	0.35	0.07	0.16
Parity 3	9.82	10.37	12.46	10.58	0.42	0.29	0.21

SEM, standard error of the means; ME, metabolizable energy; EBW, empty body weight.
1) Energy intake ME kcal/kg.
2) Prediction of equation from Dourmad et al [4]: $-26.4+0.221\times$(EBW, kg)$+1.331\times$(Backfat, mm).
3) Prediction of equation from Dourmad et al [4]: $2.28+0.178\times$(EBW, kg)$+0.333\times$(Backfat, mm).

were also not affected by dietary energy level (Table 10).

DISCUSSION

During gestation, the maternal BW of sows should gain 25 kg per parity over three or four parities [7]. During the gestation period there is a total 45 kg of weight gain by the sow; 20 kg is the weight of the placental and other products of conception out of the total weight [8]. In this study, all treatments showed a 45 kg of body weight gain during gestation except the 3,100 kcal/kg ME treatment in the first parity. This result demonstrated that an energy level of 3,100 kcal/kg ME might not be high enough to increase the BW during gestation. In backfat thickness, all treatments produced a backfat thickness greater than 20 mm backfat at farrowing and 16 mm at weaning. Averette Gatlin et al [9] suggested that the effect of the energy level during gestation on BW and body weight gain is highly related to the BW, which may be attributed to a higher backfat thickness due to a higher energy level [2]. However, Young et al [10] indicated that higher energy intake during gestation reduced the voluntary feed intake during lactation. Our results suggested that BW and backfat loss increased with dietary energy level in the first parity, which was in agreement with previous studies, and demonstrated that the provision of high energy feed during gestation caused increased BW and a loss of backfat thickness during lactation [2].

Fat tissue and protein tissue were increased during gestation, whereas fat and protein mass decreased with increasing energy level during lactation in the first parity, indicating that the energy supply was important factor to maintain adequate BW and back fat thickness for subsequent reproductive cycles in sows. These results were in agreement with previous studies, which demonstrated that N retention was increased by a high energy level [11] and higher feed intake during gestation [12].

Previous studies suggested that unbalanced nutrient intake caused several common reproductive problems, such as an increase in the interval from weaning to estrus [13], an increased incidence of anestrus after weaning, and a decreased conception rate [14]. However, in this study, WEI was not affected by treatment, and the 3,100 kcal/kg ME treatment had the highest culling rate (68%) because of pregnancy failure and anestrus after weaning, which was in agreement with Kongsted [15], who suggested that a low energy intake during gestation might increase the risk of culling. It is well documented that a late WEI is related to a high glucose and low FFA concentration in weaned sows [16]. In this study, the plasma glucose

Table 5. Effects of energy level on the estimated fat and protein mass of lactating sows over three consecutive parities

Criteria	Treatment				SEM	p-value	
	3,100[1)]	3,200	3,300	3,400		Linear	Quadratic
Estimated fat mass[2)] on lactation (kg)							
Farrowing							
Parity 1	36.58	35.79	35.72	38.43	0.99	0.51	0.38
Parity 2	40.74	44.09	42.85	42.00	1.36	0.69	0.39
Parity 3	42.57	46.19	48.61	51.32	1.86	0.20	0.82
Weaning							
Parity 1	35.75	35.32	35.21	33.40	0.97	0.44	0.73
Parity 2	32.51	39.48	37.58	34.94	1.24	0.68	0.11
Parity 3	42.28	44.47	48.30	47.54	1.70	0.41	0.87
Gain (Farrowing to weaning, kg)							
Parity 1	–0.83	–0.47	–0.51	–5.03	0.62	0.02	0.03
Parity 2	–8.23	–4.61	–5.27	–7.07	1.10	0.95	0.29
Parity 3	–0.29	–1.72	–0.31	–3.78	0.75	0.28	0.41
Estimated protein[3)] mass on lactation (kg)							
Farrowing							
Parity 1	37.44	37.36	36.91	38.40	0.36	0.47	0.28
Parity 2	41.26	43.17	42.35	42.18	0.54	0.52	0.29
Parity 3	43.05	46.29	46.96	47.78	0.81	0.09	0.76
Weaning							
Parity 1	38.34	38.16	37.59	36.95	0.40	0.16	0.70
Parity 2	37.53	41.59	39.77	38.95	0.55	0.60	0.05
Parity 3	43.83	46.06	47.14	46.90	0.78	0.30	0.69
Gain (Farrowing to weaning, kg)							
Parity 1	0.90	0.80	0.67	–1.46	0.28	0.01	0.03
Parity 2	–3.72	–1.57	–2.58	–3.23	0.40	0.97	0.14
Parity 3	0.78	–0.23	0.18	–0.88	0.34	0.19	0.81

SEM, standard error of the means; ME, metabolizable energy; EBW, empty body weight.
1) Energy intake ME kcal/kg.
2) Prediction of equation from Dourmad et al [4]: –26.4+0.221×(EBW, kg)+1.331×(Backfat, mm).
3) Prediction of equation from Dourmad et al [4]: 2.28+0.178×(EBW, kg)+0.333×(Backfat, mm).

and FFA concentration of sows at weaning was not affected by treatment, indicating that the dietary energy level did not affect the WEI.

Prunier et al [17] suggested that there was no treatment effect on number of embryos when the energy intake was increased from moderate (28 MJ d/ME) to high (37 MJ d/ME).

Table 6. Effects of dietary energy level on the lactation feed intake, weaning to estrus interval after lactation and culling rate of sows over three consecutive parities

Criteria	Treatment				SEM	p-value	
	3,100[1)]	3,200	3,300	3,400		Linear	Quadratic
No. of sows							
Initial	13	13	13	13	-	-	-
Parity 1	8	12	12	11	-	-	-
Parity 2	6	9	9	8	-	-	-
Parity 3	4	8	8	8	-	-	-
Daily feed intake (kg/d)							
Parity 1	5.99	5.77	5.79	5.32	0.11	0.08	0.16
Parity 2	5.34	5.62	5.21	4.47	0.24	0.22	0.47
Parity 3	6.08	6.18	5.97	6.13	0.17	0.89	0.91
WEI (d)							
Parity 1	5.29	5.27	5.17	5.67	0.18	0.99	0.20
Parity 2	5.43	5.66	5.17	6.00	0.37	0.56	0.92
Parity 3	7.25	5.25	5.42	5.43	0.31	0.16	0.16
Sow removals (head)							
Reproductive failure	9	5	5	4	-	-	-
Lameness	0	0	0	1	-	-	-
Culling rate (%)							
Parity 1 to 3	69.00	38.00	38.00	38.00	-	-	-

SEM, standard error of the means; WEI, weaning to estrus interval; ME, metabolizable energy.
1) Energy intake ME kcal/kg.

Table 7. Effects of dietary energy level on the reproductive performance of sows over three consecutive parities

Criteria	Treatment				SEM	p-value	
	3,100[1)]	3,200	3,300	3,400		Linear	Quadratic
Total born[2)]							
Parity 1	12.11	13.00	12.33	12.00	0.33	0.36	0.66
Parity 2	12.86	14.00	13.50	13.91	0.44	0.52	0.71
Parity 3	15.00	12.50	13.43	14.14	0.53	0.75	0.13
Born alive/litter							
Parity 1	11.44	12.27	11.75	11.54	0.33	0.42	0.76
Parity 2	11.86	13.11	12.33	12.91	0.42	0.52	0.59
Parity 3	14.00	11.63	12.57	13.29	0.46	0.77	0.06
Still births/litter							
Parity 1	0.67	0.73	0.58	0.46	0.08	0.61	0.56
Parity 2	1.29	0.89	1.00	1.00	0.21	0.79	0.53
Parity 3	1.00	0.88	0.86	0.86	0.22	0.84	0.99
After fostering[3)]							
Parity 1	11.33	11.18	11.25	11.62	0.24	0.65	0.31
Parity 2	11.43	11.56	11.75	11.40	0.16	0.97	0.58
Parity 3	11.50	11.50	11.57	11.43	0.21	0.77	0.74
Weaning pigs							
Parity 1	11.00	10.27	10.58	11.31	0.24	0.66	0.02
Parity 2	10.43	11.11	11.08	11.10	0.19	0.42	0.44
Parity 3	11.00	10.38	11.29	10.57	0.31	0.83	0.72

SEM, standard error of the means; ME, metabolizable energy.
1) Energy intake ME kcal/kg. 2) Registered litter size. 3) After cross-fostering day at d 1 postpartum.

Also, previous studies suggested that a high energy supply (50.1 and 48.6 MJ d/ME) 3 days after mating or immediately after mating did not affect the number of embryos or the litter size in sows [18,19]. Similar results were also observed in this study.

It is well documented that increased energy intake during late gestation can positively affect fetal growth [3]. However,

Table 8. Effects of dietary energy level on the progeny growth performance of sows over three consecutive parities

Criteria	Treatment				SEM	p-value	
	3,100[1)]	3,200	3,300	3,400		Linear	Quadratic
Average litter weight (kg)							
Litter birth weight[2)]							
Parity 1	14.47	16.03	15.42	15.29	0.44	1.00	0.62
Parity 2	17.92	20.01	20.75	20.13	0.60	0.24	0.33
Parity 3	20.80	18.12	19.72	19.64	0.57	0.70	0.24
Initial litter weight[3)]							
Parity 1	14.29	14.30	14.40	14.59	0.43	0.85	0.77
Parity 2	16.80	17.20	17.86	17.39	0.41	0.62	0.64
Parity 3	17.02	17.82	18.16	17.26	0.57	0.83	0.71
d 21 litter weight							
Parity 1	58.16	56.82	57.49	63.55	1.36	0.31	0.19
Parity 2	51.20	52.67	55.08	52.37	1.52	0.97	0.57
Parity 3	65.38	64.51	68.06	63.41	1.95	0.80	0.44
Average piglet weight (kg)							
Piglet birth weight[2)]							
Parity 1	1.19	1.25	1.25	1.30	0.03	0.23	0.96
Parity 2	1.55	1.62	1.69	1.58	0.05	0.85	0.58
Parity 3	1.42	1.53	1.51	1.44	0.06	0.87	0.40
Initial piglet weight[3)]							
Parity 1	1.26	1.28	1.27	1.26	0.03	0.94	0.82
Parity 2	1.47	1.49	1.52	1.52	0.03	0.51	0.85
Parity 3	1.48	1.55	1.57	1.51	0.05	0.77	0.46
d 21 piglet weight							
Parity 1	5.35	5.56	5.47	5.64	0.09	0.10	0.60
Parity 2	4.91	4.71	4.97	4.72	0.10	0.49	0.95
Parity 3	5.94	6.26	6.11	5.97	0.15	0.99	0.49

SEM, standard error of the means; ME, metabolizable energy.
1) Energy intake ME kcal/kg. 2) Registered litter size. 3) After cross-fostering day at d 1 postpartum.

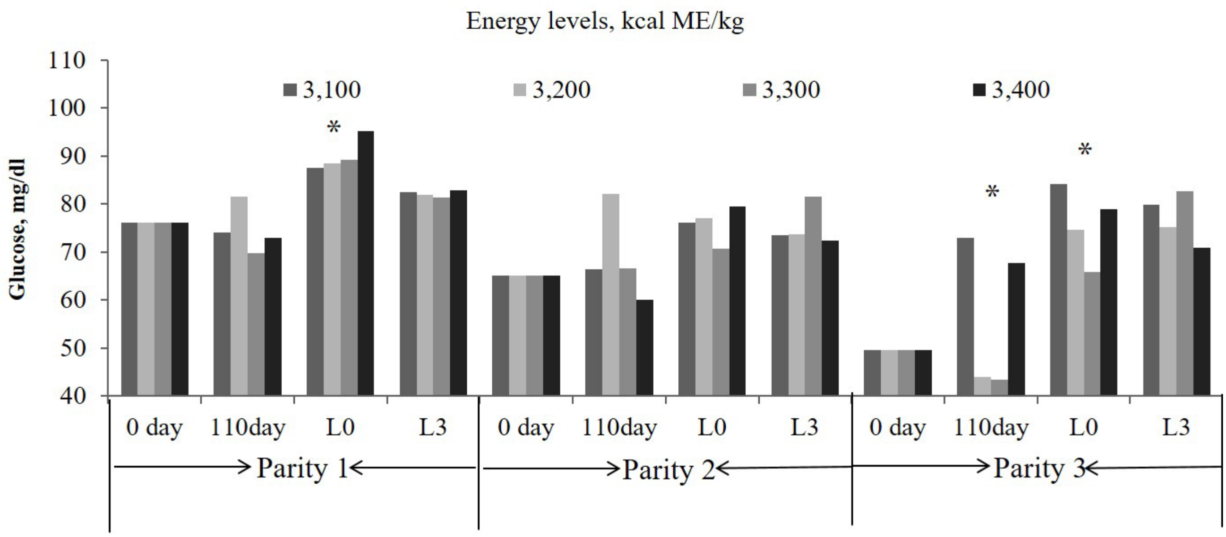

Figure 1. Effects of the dietary energy level on the blood urea nitrogen concentration in the blood of sows over three consecutive parities (* p<0.1).

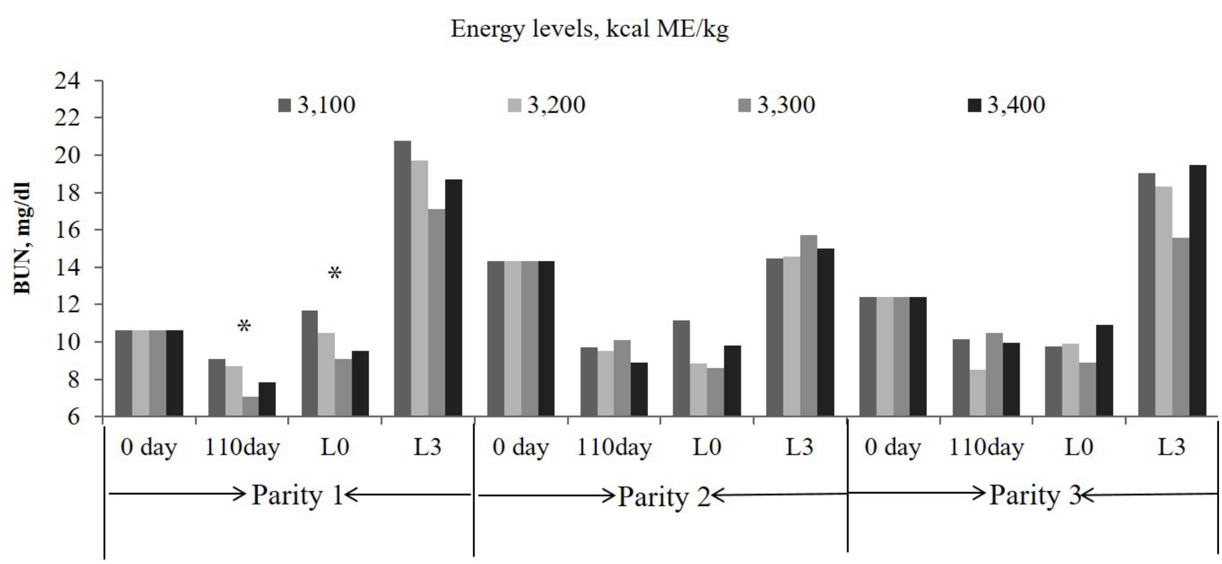

Figure 2. Effects of the dietary energy level on the glucose concentration in the blood of sows over three consecutive parities (* p<0.1).

no effect was observed on litter birth weight and individual piglet birth weight (Table 8), which was consistent with results of Long et al [2], who demonstrated that the average piglet BW at farrowing was not affected by different energy levels in the gestation diet. Similarly, Piao et al [20] also suggested that an increased feed intake during gestation did not increase litter weight or individual piglet weight. In this study, the 3,400 kcal ME/kg treatment showed the highest weaning litter size in the first parity. However, feed intake decreased in the 3,400 kcal ME/kg treatment more than the other treatments with an increased BW, backfat thickness loss, and a decreased culling rate.

It is very well known that BUN is connected to retention of nitrogen in the body [21]. In this study, the serum BUN concentration tended to decrease with an increasing energy level at 110 days of gestation and 24 hours post-farrowing in the first parity, which was consistent with the results of Ruiz et al [22], who reported that the BUN concentration was lower in swine that were fed a high energy diet compared to pigs fed a low energy diets. These results might suggest that the energy intake in sows affects the protein metabolism during gestation. An increased energy level during gestation could decrease glucose utilization and subsequently feed intake during lactation [23]. Moreover, an increased feed intake in gestating gilts may cause sows to become insensitive to insulin, which presents a smaller response in glucose clearance and decreased feed during lactation [20]. In this study, the glucose concentration was increased with a higher energy level 24 hours post-farrowing in the first parity, but was lowest in the 3,300 kcal/kg

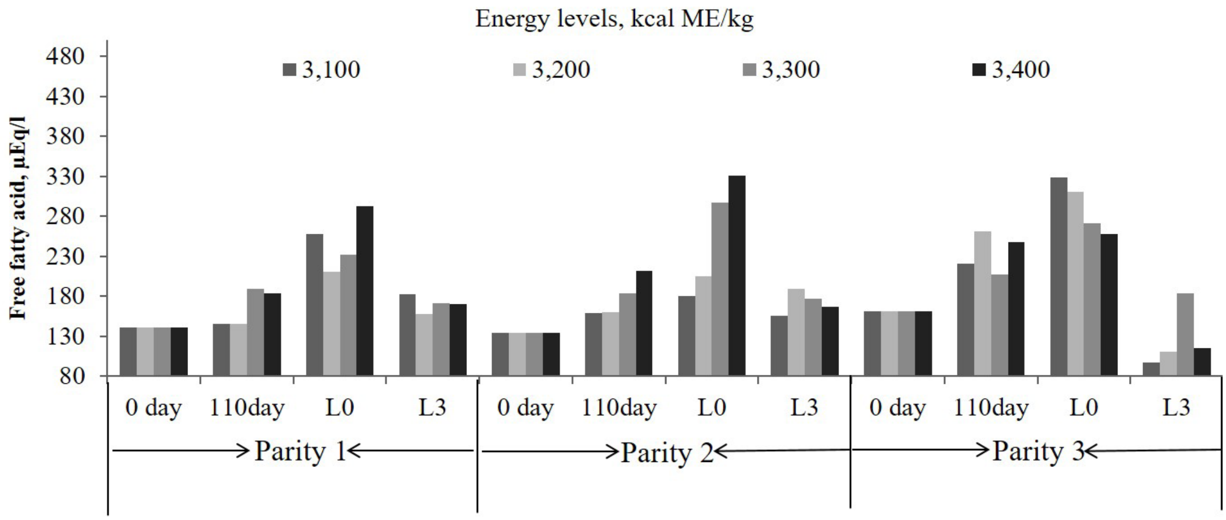

Figure 3. Effects of the dietary energy level on the free fatty acid concentration in the blood of sows over three consecutive parities

ME treatments at 110 days of gestation and 24 hours post- farrowing in the third parity. Therefore, the effect of insulin on feed intake during lactation might depend on the body condition of the sows and the glucose metabolites, and this can explain our results of higher bodyweight and backfat thickness loss with an increased energy level during lactation in parity 1, but not in parity 3.

The chemical composition of the colostrum and milk of

Table 9. Effects of dietary energy level in gestating sows on the fat content in colostrum and milk of lactating sows over three consecutive parities

Criteria	Treatment				SEM	p-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
Fat content in colostrum[2] (%)							
Parity 1	6.44	7.40	7.33	7.67	0.36	0.69	0.24
Parity 2	8.99	9.77	11.30	9.09	0.42	0.43	0.20
Parity 3	7.78	7.15	9.43	8.01	0.38	0.36	0.58
Fat content in sow milk at d 21 postpartum (%)							
Parity 1	5.56	7.01	6.58	6.86	0.21	0.10	0.06
Parity 2	6.20	6.28	6.65	7.22	0.23	0.13	0.62
Parity 3	6.67	6.74	7.69	7.14	0.30	0.32	0.56

SEM, standard error of the means; ME, metabolizable energy.
[1] Energy intake ME kcal/kg. [2] 24 hours post-farrowing.

Table 10. Effects of dietary energy level in gestating sows on the fatty acids compositions of colostrum in primiparous lactating sows over three consecutive parities (mg/g)

Criteria	Treatment				SEM	p-value	
	3,100[1]	3,200	3,300	3,400		Linear	Quadratic
Fatty acid composition of colostrum at 24 h postpartum (mg/g)							
Saturated fatty acid							
Parity 1	11.11	13.28	13.49	9.14	1.360	0.63	0.23
Parity 2	12.07	14.57	14.00	12.24	1.340	1.00	0.53
Parity 3	8.78	13.05	13.57	9.55	1.200	0.81	0.14
Monounsaturated fatty acid							
Parity 1	15.07	18.43	20.97	13.77	2.150	0.95	0.25
Parity 2	17.88	20.62	21.46	18.11	2.000	0.94	0.54
Parity 3	13.28	18.47	19.82	14.62	1.740	0.75	0.19
Polyunsaturated fatty acid							
Parity 1	6.93	7.85	8.91	5.46	0.800	0.65	0.20
Parity 2	7.29	7.79	7.42	6.27	0.830	0.71	0.70
Parity 3	4.93	7.55	7.30	4.81	0.740	0.93	0.14

SEM, standard error of the means; ME, metabolizable energy.
[1] Energy intake ME kcal/kg.

sows is variable due to the dietary regimen [24] and the body condition of the sows [25]. Feeding a fatty diet in late gestation increased the total lipids in colostrum [26]. However, Yang et al [27] reported that there was no effect on the colostrum composition when the energy level was increased from 13.7 to 14.2 MJ of ME/kg in the gestation diet. In this study, no significant difference in the fat content of sow colostrum and milk was noted, which is in agreement with Williams et al [28], who demonstrated that the chemical composition of colostrum and milk was not affected by dietary energy level during gestation because the sow mobilized its body reserves to compensate for the nutrient deficiency.

The fatty acid composition of colostrum was affected by the dietary fat level [29] and type of fat provided in the diet [30], which was inconsistent with our results, which showed that the fatty acids composition of colostrum was not influenced by energy level during gestation. However, studies on the effect of energy level during gestation on the fatty acid composition of colostrum are limited, and further studies are still warranted to elucidate a detailed mechanism. Consequently, the adequate energy intake of gestating sows was 6,400 or 6,600 kcal of ME/d for parity 1, 7,040 or 7,260 kcal of ME/d for parity 2, and 7,680 or 7,920 kcal of ME/d for parity 3.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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