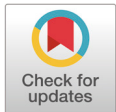


# Effects of free feeding time system and energy level to improve the reproductive performance of lactating sows during summer

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Received: Feb 6, 2020  
Revised: Mar 27, 2020  
Accepted: Apr 6, 2020

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## Abstract

The reproductive performance of lactating sows was investigated by using different feeding methods including conventional feeding (CF, 3 times/d) or free feeding (FF), and different dietary energy level including low energy (LE: 3,300) or high energy (HE: 3,400 kcal/kg) during the hot season. A total of twenty-eight crossbred (Yorkshire × Landrace) sows were distributed into four treatments as a 2 × 2 factorial arrangement. Sows in the FF group showed lower body weight and backfat loss ( $p < 0.05$ ) compared with the CF group. Backfat loss during lactation was lower ( $p < 0.05$ ) in sows fed HE diet than in that fed LE diet. There were no significant differences in litter survival rate and weaning to estrus interval, but the litter weight at weaning was improved ( $p < 0.05$ ) in FF and HE sows. Hence, it is concluded that using the free-feeding system or increased dietary energy density leads to improved sow performance during hot ambient temperature.

**Keywords:** Energy, Feeding, Heat stress, Lactating sows, Piglets

## INTRODUCTION

The major goal in the management of lactating sow is to enhance the capacity of voluntary feed intake to increase milk yield, preventing the excess body weight (BW) loss, and achieving a prompt weaning-to-estrus interval (WEI). Voluntary feed intake, litter growth, milk output, and WEI of sows can be compromised in the farrowing time during the heat stress period [1–3]. Wolp et al. [4] and Kim et al. [5] indicated that the adverse influences of heat stress can be related to the undeveloped physiological control of body temperature and insufficient function of sweating through the skin due to keratinized sweat glands, and thick subcutaneous fat layer.

The voluntary feed intake is the most common thermoregulatory mechanism in swine to diminish the adverse effects of high environmental temperature [6,7]. Although the reduced feed intake may minimize heat load during heat stress conditions and adversely impact the growth performance. Espe-

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#### Competing interests

No potential conflict of interest relevant to this article was reported.

#### Funding sources

The work was supported by the Cooperative Research Program for Agriculture Science and Technology Development (grant No. 01160302), Rural Development Administration, Korea. This study has been worked with the support of a research grant of Kangwon National University in 2018.

#### Acknowledgements

Not applicable.

#### Availability of data and material

Upon reasonable request, the datasets of this study can be available from the corresponding author.

#### Authors' contributions

Conceptualization: Kim TG, Chae BJ.  
 Data curation: Kim TG, Lee JH.  
 Formal analysis: Kim MJ, Moturi J.  
 Methodology: Kim KY, Choi YH.  
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 Validation: Song CH, Lee JH.  
 Investigation: Kim KY, Choi YH.  
 Writing - original draft: Kim KY.  
 Writing - review & editing: Lee JH.

#### Ethics approval and consent to participate

This experiment was aligned to the ethical standards of animal (KW-170519-1) in Institutional Animal Care and Use Committee of Kangwon National University, Chuncheon, Korea.

cially, the high humidity in summer months in Korea increases the disadvantage of high temperatures. Nutritional strategies to obtain adequate feed intake can positively increase lactating sows performance. As the conventional feeders are designed to be incorporated with waterers, the on-time feed release may allow the sow to eat the meal completely and avoid unsound fermentation and decomposition of feed in the presence of water during high temperatures. Therefore, it can be assumed that this method may increase the efficiency of feeding by reducing the waste of water and feed. Although many researchers were studying feed intake under high ambient temperature, there are limited studies regarding the efficacy of automatic feeders in lactating sows. Thus, the main aim of the current study was to evaluate the influences of temperature in commercial swine farm and seasonal changes in daily feed intake of lactating sows.

## MATERIALS AND METHODS

The experimental design for the current study was permitted by the Committee of Institutional Animal Care and Use at Kangwon National University, Chuncheon 24341, Korea.

### Animals and management

A total of twenty-eight crossbred sows (Yorkshire × Landrace; average BW, 233.5 ± 23.4 kg and 3.60 parity) were divided between four treatments after farrowing as a 2 × 2 factorial arrangement. The treatments were included two feeder types (CF, conventional feeding and 3 times/d; FF, free-feeding) and two levels of energy (low energy, 3,300 kcal/kg and high energy, 3,400 kcal/kg). *Ad libitum* access to feed was provided for all lactating sows. Freshwater was available via a drinker situated in the feeder. The feeders (0.46 m × 0.36 m × 0.36 m) in CF treatment were controlled and refilled three times daily. Newly designed free-feeding feeders (KOCA, Seoul, Korea) were applied for sows in FF treatment. The FF system in this study was designed to release 200 grams of feed per meal as soon as the feeder is touched by the sow. Moreover, two minutes delay was programmed between the meals to avoid over feed release. In addition, a probe was placed in the watering pipe to restrict the release of water if the frequent touch of the waterer nipple was done by the sow due to high ambient temperature. The artificial insemination was performed 2 times at the onset of estrus, and the pregnancy confirmation test was done at d thirty post-breeding by an ultrasound machine (Pharvision B-mode, Ambisea Tech., Shenzhen, China). The diets were balanced based on the National Research Council (2012) standard for lactation requirements for all the treatments (Table 1). The average temperature of 28.1 °C ± 1.1 °C was recorded in the conventional farrowing rooms.

### Data collection and measurement

The evaluation of live weight was performed on d 109 of gestation (before farrowing) and d 21 of lactation (at weaning). An ultrasonic device (Agroscan A16, France) was used for the backfat thickness (BFT) measurement on d 109 of gestation and d 21 of lactation at the 10th rib. The BFT change during lactation was calculated by measuring the difference between BFT at d 21 of lactation and BFT at d 109 of gestation. Litter performance traits including the number of born and born alive piglets, BW (kg) at farrowing and weaning, and the number of weaned piglets were recorded. In addition, the amount of feed intake and the duration of WEI were detected. The average daily gain (ADG) of weanling piglets was measured.

### Blood metabolites

The blood samples (10-mL per sample) were collected on the farrowing day (day 1 of lactation) and on d 21 (weaning) of lactation by a heparin-free vacutainer tube (Becton Dickinson, Franklin,

**Table 1. Formula and chemical composition of lactation sow diets (as-fed basis)**

ME (kcal/kg)	Low energy	High energy
Ingredients (%)	100.00	100.00
Corn	62.50	60.56
SBM	28.60	28.30
Animal fat	2.63	4.75
Molasses	2.00	2.00
TCP	1.54	1.58
Limestone	1.48	1.55
Salt	0.50	0.50
Choline chloride (50%)	0.05	0.05
L-Lysine-HCl (78%)	0.05	0.05
DL-Methionine (99.8%)	-	0.02
L-Threonine (98.5%)	0.03	0.03
L-Tryptophan (10%)	0.18	0.17
L-Valine (98.5%)	0.09	0.09
Vitamin premix <sup>1</sup>	0.15	0.15
Mineral premix <sup>2</sup>	0.15	0.15
Phytase	0.05	0.05
Calculated composition (g/100 g DM)		
ME (kcal/kg)	3,300	3,400
CP	17.80	17.80
Ca	0.88	0.88
Av. P	0.44	0.44
SID. Arg	1.03	1.03
SID. His	0.41	0.41
SID. Ile	0.62	0.62
SID. Leu	1.36	1.36
SID. Lys	0.88	0.88
SID. Met	0.23	0.23
SID. Met + Cys	0.48	0.48
SID. Thr	0.56	0.56
SID. Trp	0.18	0.18
SID. Val	0.75	0.75

<sup>1</sup>Supplied per kilogram of vitamin premix: 12,000,000 IU vitamin A, 2,400,000 IU vitamin D<sub>3</sub>, 132,000 IU vitamin E, 1,500 mg vitamin K<sub>3</sub>, 3,000 mg vitamin B<sub>1</sub>, 11,250 mg vitamin B<sub>2</sub>, 3,000 mg vitamin B<sub>6</sub>, 45 mg vitamin B<sub>12</sub>, 36,000 mg pantothenic acid, 30,000 mg niacin, 600 mg biotin, 4,000 mg folic acid.

<sup>2</sup>Supplied per kilogram of mineral premix: 80,000 mg Fe, 170 mg Co, 8,500 mg Cu, 25,000 mg Mn, 95,000 mg Zn, 140 mg I, 150 mg Se.

ME, metabolizable energy; SBM; soybean meal; TCP, tricalcium phosphate; SID, standardized ileal digestibility.

NJ) from jugular vein between 08:30 and 09:30. The blood plasma was separated by centrifugation (3,000×g for 15 min at 4°C) and stored at -20°C for blood metabolites analysis including blood urea nitrogen, triglyceride, glucose, creatinine, and insulin. An automated chemistry analyzer (Fuji Dri-chem 3500i, Fujifilm) and commercial kits (Fujifilm, Saitama, Japan) were used for the analysis of blood metabolites.

### Hormone profiles

At d 1 and d 21 of lactation, 10 mL blood samples were collected after 09:00 meal at 60-minute intervals (from 09:00 to 13:00) for 4 h to analyze luteinizing hormone (LH) and follicle-stimulating hormone (FSH). Swine insulin, FSH, and LH kits (Endocrine Technologies, Newark, CA, USA) were applied and the concentrations of hormones were measured (in duplicate) with the ELISA method by Biolog Micro Station system. The intra-assay coefficient of variation (CV) for insulin, LH, and FSH were 2.66%, 14.68%, and 8.81%, and inter-assay CV was 17.32%, 5.35%, and 18.14%, respectively.

### Colostrum and milk composition

The evaluation of milk and colostrum (25 mL sample) composition including total solid, protein, fat, and lactose was performed at d 1 and d 10 postpartum. One mL of oxytocin (1 U/mL) was applied intravenously to stimulate lactating sow milk release. Milk was manually collected from all functional teats. At the next step, milk and colostrum samples were frozen at  $-20^{\circ}\text{C}$  to analyze the parameters by Milko Scan infrared milk analyzer (Foss Electric, Hillerød, Denmark).

### Statistical analyses

The GLM procedure of the SAS package (SAS, 2012; SAS Inst., Cary, NC, USA) was applied for statistical analysis as a  $2 \times 2$  factorial arrangement and a complete block design. The main effects of feeding types and energy levels and their interaction terms were considered in the statistical model. The significant differences were separated by using Tukey's honestly significant difference test. In all variables analyzed, the individual sow was identified as an experimental unit. Probability values of  $< 0.05$  were considered significant.

## RESULTS

### Sow performance

The body condition result, daily feed intake, and WEI of sows are presented in Table 2. There was no interaction between the energy level and feeder type for the measured variables. The BW change and daily feed intake during lactation were significantly effected ( $p < 0.05$ ) by the FF treatment. Energy level had no effects on BW, BFT, daily feed intake and WEI of lactating sows during the summer season.

### Litter performance

The influence of feeder type and energy level on litter performance is shown in Table 3. There were no significant effects of feeder type and energy level on litter size, piglets weaned, and survival rate. The litter weight at weaning, total weight gain, and average weight gain were increased in the FF and high energy diet treatments.

### Blood metabolites

Blood metabolites of sows are shown in Table 4. There were no significant effects between the feeding type and energy level on blood urea nitrogen, glucose, triglyceride, and creatinine at post farrowing and weaning times during the summer season.

### Hormone profiles

The effects of feeder type and energy level are shown in Table 5. There were no interaction effects between feeder type and energy level on hormone profiles ( $p > 0.05$ ). There were no significant

**Table 2. Effects of feeding type and dietary energy level on backfat thickness change, feed intake and weaning to estrus interval in sows during summer season**

Item <sup>1)</sup>	Feeding type		Energy level (ME, kcal/kg)		SEM	p-value		
	CF	FF	3,300	3,400		F	E	F × E
Parity	3.61	3.52	3.59	3.51	0.37	0.701	0.998	0.848
Sow body weight (kg)								
Gestation (d 109)	233.53	231.08	233.92	230.68	6.51	0.517	0.834	0.660
Weaning	214.92	215.37	215.55	214.74	6.00	0.828	0.875	0.724
Change (–)	18.61	15.71	18.37	15.94	1.34	0.031	0.084	0.579
Sow backfat thickness (mm)								
Gestation (d 109)	20.92	20.99	21.23	20.68	0.69	0.934	0.538	0.750
Weaning	16.67	17.36	16.92	17.11	0.44	0.182	0.537	0.298
Change (–)	4.26	3.62	4.31	3.57	0.37	0.089	0.070	0.517
Daily feed intake (kg/d)	4.52	5.13	4.93	4.73	0.11	0.001	0.124	0.401
Weaning to estrus interval (d)	5.25	4.71	5.14	4.82	0.38	0.169	0.407	0.926

<sup>1)</sup>Data are means of seven replicates.

SEM, Standard error of means; CF, conventional feeding; FF, free feeding; F, feeding type, E, dietary energy level, F × E, feeding type × dietary energy level.

**Table 3. Effects of feeding type and dietary energy level on litter size and piglet performance in sows during summer season**

Item <sup>1)</sup>	Feeding type		Energy level (ME, kcal/kg)		SEM	p-value		
	CF	FF	3,300	3,400		F	E	F × E
Litter size								
Initial litter size	11.68	11.74	11.67	11.75	0.23	0.997	0.541	0.361
Piglets weaned	11.25	11.40	11.22	11.43	0.25	0.673	0.326	0.482
Survival rate (%)	96.38	97.11	96.13	97.36	1.13	0.459	0.331	0.825
Litter weight (kg)								
Initial (d 1)	15.95	16.28	16.10	16.14	0.36	0.646	0.587	0.548
Initial (kg/pig, d 1)	1.37	1.39	1.38	1.38	0.01	0.312	0.944	0.759
Weaning (d 21)	69.01	73.92	69.88	73.05	1.61	0.006	0.033	0.833
Weaning (kg/pig, d 21)	6.14	6.49	6.23	6.40	0.06	0.001	0.007	0.195
Total weight gain	53.06	57.65	53.79	56.92	1.35	0.002	0.017	0.932
Average weight gain (g/pig)	224.27	240.88	228.18	237.17	3.08	0.001	0.002	0.466

<sup>1)</sup>Data are means of seven replicates.

SEM, standard error of means; CF, conventional feeding; FF, free feeding; F, feeding type, E, dietary energy level, F × E, feeding type × dietary energy level.

**Table 4. Effects of feeding type and dietary energy level on blood metabolites of lactating sows during summer season**

Item <sup>1)</sup>	Feeding type		Energy level (ME, kcal/kg)		SEM	p-value		
	CF	FF	3,300	3,400		F	E	F × E
Post farrowing (mg/dL)								
Blood urea nitrogen	19.52	19.74	19.40	19.86	0.91	0.810	0.622	0.746
Glucose	93.57	90.12	91.96	91.72	4.12	0.408	0.954	0.602
Triglyceride	42.21	42.58	42.09	42.70	2.88	0.898	0.832	0.562
Creatinine	2.15	2.12	2.15	2.12	0.10	0.745	0.812	0.289
Weanling (mg/dL)								
Blood urea nitrogen	20.98	20.49	20.96	20.51	0.95	0.610	0.643	0.446
Glucose	92.57	97.13	94.03	95.67	5.78	0.443	0.782	0.941
Triglyceride	24.67	26.84	25.18	26.33	1.41	0.130	0.419	0.891
Creatinine	1.69	1.62	1.65	1.66	0.10	0.458	0.882	0.703

<sup>1)</sup>Data are means of seven replicates.

SEM, standard error of means; CF, conventional feeding; FF, free feeding; F, feeding type, E, dietary energy level, F × E, feeding type × dietary energy level.

effects on the FSH, LH, cortisol, and insulin of post farrowing and weaning sows during the summer season ( $p > 0.05$ ).

### Milk and colostrum composition

Colostrum and milk composition are shown in Table 6. There were no feeder type and energy level interactions for any of the measured variables. The colostrum and milk composition of lactating sows were unaffected by the feeder type and energy level during the summer season.

## DISCUSSION

In this study, the BW change and daily feed intake change were reduced in the FF sows. Moreover, there was a tendency towards significantly reduced BFT in the FF sows. It is commonly recognized that the BFT and negative energy balance affect the reproductive performance of sows in subsequent parities [8,9]. Furthermore, the higher fluctuations in the pattern of feed intake and milk yield decrease the BFT uniformity and increase the BFT loss at weaning [9,10]. The variation in

**Table 5. Effects of feeding type and dietary energy level on hormone profiles of lactating sows during summer season**

Item <sup>1)</sup>	Feeding type		Energy level (ME, kcal/kg)		SEM	p-value		
	CF	FF	3,300	3,400		F	E	F × E
Post farrowing								
FSH (ng/mL)	1.96	1.96	1.97	1.95	0.05	0.942	0.672	0.478
LH (ng/mL)	0.35	0.34	0.35	0.33	0.03	0.818	0.541	0.756
Insulin (uU/mL)	2.36	2.39	2.40	2.35	0.28	0.926	0.867	0.629
Cortisol (ug/mL)	8.17	8.02	8.25	7.94	0.39	0.695	0.435	0.925
Weaning								
FSH (ng/mL)	2.73	2.80	2.74	2.79	0.12	0.597	0.733	0.984
LH (ng/mL)	0.63	0.67	0.64	0.66	0.05	0.438	0.633	0.911
Insulin (uU/mL)	1.40	1.58	1.45	1.53	0.10	0.074	0.506	0.870
Cortisol (ug/mL)	5.02	4.32	4.89	4.44	0.46	0.132	0.327	0.601

<sup>1)</sup>Data are means of seven replicates.

SEM, standard error of means; CF, conventional feeding; FF, free feeding; F, feeding type, E, dietary energy level, F × E, feeding type × dietary energy level.

**Table 6. Effects of feeding type and dietary energy level on colostrum and milk composition of lactating sows during summer season**

Item <sup>1)</sup>	Feeding type		Energy level (ME, kcal/kg)		SEM	p-value		
	CF	FF	3,300	3,400		F	E	F × E
Colostrum (%)								
Total solid	23.53	22.35	21.91	22.92	1.22	0.669	0.943	0.372
Protein	15.65	15.32	14.70	15.19	0.44	0.220	0.853	0.349
Fat	5.44	5.14	5.05	5.31	0.33	0.756	0.947	0.399
Lactose	3.56	3.35	3.26	3.43	0.15	0.479	0.885	0.214
Milk (%)								
Total solid	17.53	18.26	18.47	18.83	0.98	0.444	0.582	0.849
Protein	5.46	5.65	5.89	6.08	0.30	0.162	0.525	0.993
Fat	7.08	7.28	7.36	7.61	0.34	0.373	0.510	0.937
Lactose	5.07	5.24	5.38	5.55	0.42	0.464	0.699	0.993

<sup>1)</sup>Data are means of seven replicates.

SEM, standard error of means; CF, conventional feeding; FF, free feeding; F, feeding type, E, dietary energy level, F × E, feeding type × dietary energy level.

sow's BFT and BW during lactation are associated with feed intake, however, they may be related to the stress patterns as well as the result of this study also showed a decreased piglet ADG in the CF lactating sows during summer. Acute heat stress has severe adverse effects on BW, which are related to the limited voluntary feed intake [11]. In addition, energy expenditure is much higher during heat stress due to body thermoregulation [12,13]. There is a positive relationship between the feed intake pattern and energy requirement during lactation because a big share of the required energy is allocated to milk production [9]. Thus, improving the feed intake pattern is crucial to increase voluntary feed intake. Supplemental fat in lactation diets has been reported to be beneficial [14–16], particularly when sows are exposed to high ambient temperature [12,17,18]. However, this study showed no relationship between the energy level and BW, BFT, daily feed intake, and WEI.

In the present study, the addition of 3,400 kcal/kg metabolizable energy (ME) increased piglet performances. Increasing the energy levels with additional fats or oils in diets is known as a nutritional strategy to support lactating sow exposed to heat stress [19,20], particularly in prolific lactating sows [9]. The increase in supplementation of fat and oil in lactation diets from 2% to 11% enhanced the energy intake of around 1,100 kcal ME per day [21]. As energy is a high nutritional priority in lactating sows, a large share of additional energy dedicates to milk production to increase the milk fat yield [21]. Therefore, the advantages of high energy consumption may explain the improvements in litter performance due to high milk yield [20,21]. Moreover, the higher voluntary feed intake has a positive relationship with the body energy reserve and milk output in lactating sows [9]. As expected, sows in the FF treatment showed a lower body weight loss but an improved litter performance.

The blood metabolites and hormone profiles were not affected by feeding type and energy level. It has been reported that reduced feed intake decreases plasma glucose levels [22]. However, the increased feed intake in the FF treatment did not result in higher blood glucose. In agreement, Farmer et al. [23] reported no change in the level of glucose in lactating sows subjected to high ambient temperature. Regarding the differences between the current study and previously reported results, a better knowledge of the influence of blood parameters during high temperature is required.

Several studies reported that higher feed intake increases the milk yield of lactating sows, which directly affects the litter growth performance [9,24]. The insignificant differences in the milk and colostrum composition in this study may suggest that the milk yield of sows in the FF and high energy diet might be improved because of the higher litter growth performance. The larger litter size in the modern farms requires substantially higher energy in lactating sows, because between 65% to 85% of energy requirements dedicates to milk production [25]. Therefore, the concentration of dietary energy by supplementing fat or oil is a determinant factor to maintain the requirement of lactating sows.

In conclusion, the free feeding time system showed a significantly greater influence on litter performance and feed intake of lactating sows during summer and can be recommended as a practical feeding system in commercial farms. Moreover, the energy level of the diet can be increased to 3,400 kcal during summer due to the increased litter performance.

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