An overview of hourly rhythm of demand-feeding pattern by a controlled feeding system on productive performance of lactating sows during summer

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ABSTRACT
The present study investigated the impacts of the conventional feeder and free feeding time (FFT), and backfat thickness (<20 mm and ≥20 mm) on sows at farrowing to weaning during the summer season. A total of 56 crossbred sows were allotted to one of four treatments according to a 2 × 2 factorial arrangement. Feeder type affected body weight changes (p < .01) and backfat losses (p < .05), and the body weight changes (p < .05) and backfat losses (p < .01) of sows were lower for those with <20 mm backfat thickness compared with those with ≥20 mm backfat thickness during the lactation period. Daily feed intake was greater in sows with lower backfat thickness (5.47 kg; p < .01) and sows in the FFT group (5.46 kg; p < .05). A greater average daily gain was observed in sows in the FFT group (p < .05). There were no effects of feeder type or backfat thickness on weaning-to-oestrus interval, blood urea nitrogen, glucose, triglyceride, creatinine, FSH and LH, or colostrum and milk composition for sows during lactation. There was a linear increase in the count of Lactobacillus spp. and coliforms in conventional feeders over time (p < .01). A linear increase was detected for acetic acid production in the conventional feeders over time (p < .01). Hence, it was concluded that controlling sows’ feeding leads to improved feed intake for sows housed in hot ambient temperatures during the summer period.

KEYWORDS
Feeder; backfat thickness; heat stress; reproduction; sows (Lactating)

Introduction
Management strategies to achieve sufficient feed intake and litter performance can benefit overall pig production. A high ambient temperature has been recognised as a strong stressor that restricts voluntary feed intake in lactating sows. In one study, decreased feed intake in long-term heat-exposed lactating sows was accompanied by high fat mobilisation from adipose tissues according to high nutrient requirements (Dourmad et al. 1998). Increasing heat increment from feed decreases the voluntary feed intake in the hot hours of the day (Quiniou and Noblet 1999). One subsequent negative consequence of heat stress in female sows is feed intake being too low to meet their nutrient requirements for milk production (Quiniou and Noblet 1999; Farmer et al. 2007). In addition to the thermal environment’s influence on decreased performance, many other in-farm management factors such as the type of waterer or feeder can affect performance. Sows require nutrients for, among other things, the maintenance of biological functions, milk production, and weaning weight to decrease tissue loss. Lactating sows receive feed two or three times per day from conventional feeders in most farms; this includes a combined waterer and feeder, and dry feed mixes with water in the feeder. The moisture content of feed positively influences sows’ feed and water intake, thus improving their feed intake and decreasing feed waste. It has been shown that the voluntary feed intake of sows given liquid feed is higher than for sows given dry feed (Kim et al. 2015). Controlling fermented feed using probiotics has shown some potential and been found to be advantageous for pig performance by eliminating deleterious microbes such as Escherichia coli from the digestive tract (Yang et al. 2015). However, uncontrolled fermentation in hot...
weather can cause deterioration and severely decreased feed quality (Niven et al. 2006). It is difficult to control feeders in hot weather, because sows touch the nipples frequently to drink water, and it releases plenty of water into the feeder. The feed remaining in the feeder due to low appetite can start fermenting due to the high temperature, especially when sows are unable to eat feed during the more hot hours of the day. Programmed time-feeding systems could be beneficial to control feeding and release feed into the feeder at the proper time. Reducing waste feed and water can also be achieved when using feeding types that also help lower the environmental impact of intensive pig farming. Compared with conventional feeders, scant information has been published regarding the performance of automated feeders for lactating sows in hot environments.

The exposure of sows to heat stress reduces their voluntary consumption (Silva et al. 2009). Inadequate feed intake will lead to the increased depletion of maternal reserves, resulting in reduced performance due to ongoing lactation and reproductive failures (Houde et al. 2010). Hence, with regard to these considerations, the negative effects of limited nutrient intake due to feed fermentation in heat stress conditions may be more pronounced in sows with lower backfat thickness.

Therefore, we hypothesised that conventional feeders for sows have weaknesses at high temperatures, which compromises sows’ performance. Therefore, the aim of the present study is to evaluate the effects of feeder type on body reserves at weaning and their mobilisation during lactation in lactating sows during the summer.

**Materials and methods**

**Animals and management**

The protocol for the present experiment was approved by the Institutional Animal Care and Use Committee of Kangwon National University, Republic of Korea. A total of 56 crossbred sows (Landrace × Yorkshire) were allotted to one of four treatments according to a 2 × 2 factorial arrangement of treatments. At farrowing, sows were assigned to two feeder types (Conventional feeders or FFT) and two level of backfat thickness (<20 or ≥20 mm) at d 107 of gestation. The measurement of backfat showed mean values (± standard deviation, SD) for low backfat (<20 mm) and high backfat (≥20 mm), 17.77 ± 2.2, and 22.14 ± 2.0 mm, respectively. After farrowing, sows had ad libitum access to water via a drinker located in the feed trough in each farrowing crate. The conventional feeders were checked three times per day to be refilled when required. The test group was fed by 28 newly designed free-feeding time (KOCA Co., Ltd, Seoul, South Korea) feeders and the control group (n = 28) by conventional feeders (46 cm × 36 cm × 36 cm). The FFT system in the current study was programmed based on releasing 200 g feed per serve as soon as sow’s touch the feeder and there was a 2 min delay between two meals. Furthermore, the watering pipe includes a probe to control releasing water if sows frequently touch the waterer nipple in hot weather (Figure 1). All sows used in the present study were artificially inseminated two times after onset of oestrus, and pregnancy was detected and confirmed at d 30 post breeding using a Pharvision B-mode ultrasound machine (AV 2100V; Ambisea Tech. Corp., Shenzhen, China). Sows were weighted at d 107 gestation and at weaning. As described by Kim et al. (2018), sow backfat thickness at 10th rib, 6.5 cm from one side of the backbone was measured at d 90, farrowing and weaning (d 25 of lactation) by using an ei-medical imaging ultrasound (Loveland, CO, USA). Changes in backfat thickness of sows during lactation were measured by calculating the difference between backfat thicknesses at d 1 of lactation and backfat thickness at weaning (d 25 of lactation). Standard litter traits like total number of piglets born per litter (TB) and number of piglets born alive per litter (BA), body weight (kg) at birth, and weaning, total weight gain (kg/sow), and ADG (g/day) were recorded. Feed intake (kg/d) of each sows and weaning-to-oestrus interval (d) were also recorded. All the sows were fed a common diet as per National Research Council (2012) requirements for lactation. This study was carried out from 29 June to 27 August 2016 (during summer season) in Kangwon National University farm. Under heat stress, the average minimum and maximum

![Figure 1. The feeder design used during the experiment in free feeding time treatment.](image)
temperatures observed in the conventional farrowing rooms (24.5 ± 3.7 and 30.5 ± 3.6°C; Figure 2) frequently exceeded 24°C.

**Chemical and microbial analyses**

To measure the concentration of volatile fatty acid (VFA), feed samples were collected directly from the feeder of each sow in conventional feeder groups (four times, 1, 3, 6 and 8 h after feeding in the morning at 8 am). These samples were immediately sealed in vinyl bags and placed on ice. Concentration of acetic acid and lactic acid samples were measured by gas chromatography (HP 6890 Plus; Hewlett Packard, Houston, TX) using a modified method by Porter and Murray (2001). One gram of the composite feed sample was diluted with 9 mL of 1% peptone broth (Becton, Dickinson and Co., Franklin Lakes, NJ, USA) and then homogenised. Viable counts of bacteria in the samples were then conducted by plating serial 10-fold dilutions. For the determination of Lactobacillus spp. (Using Man, Rogosa and Sharpe (MRS-No.288130) agar +0.200 g/L NaN₃ + 0.500 g/L L-cysteine hydrochloride monohydrate), and coliforms (violet red bile agar- No. 216695) were used. The bacterial concentrations were transformed (log) before statistical analysis.

**Blood metabolites**

On day 1 (post farrowing) and the last day of experiment, a 10-mL blood sample was collected by jugular vein puncture from eight randomly selected sows per treatment using a disposable vacutainer tube containing sodium heparin as an anticoagulant (Becton Dickinson, Franklin, NJ, USA). Serum automatic biochemical analyser (Fuji Dri-chem 3500i, Japan) applied to measure concentrations of blood urea nitrogen, glucose and triglyceride. After centrifugation (3000g for 20 min), plasma samples were separated and stored at −20°C and later analysed for concentrations of blood urea nitrogen (BUN), glucose (GLU), triacylglycerides (TG), and creatinine.

**Hormone**

On day 1 (post farrowing), and day 25 (weaning, after piglet removal) of lactation, 10-mL blood samples were collected after feeding at 60-min intervals for 4 h from 0900 to 1300 for analysis of follicle stimulating hormone (FSH) and luteinizing hormone (LH). Swine insulin, LH and FSH kits (Endocrine Technologies Inc., USA) were used and their concentrations were determined in duplicate by ELISA using Biolog MicroStation system. Intra- and interassay CV for insulin, LH and FSH were 2.43 and 12.32, 7.65 and 15.90, and 4.71 and 16.86%, respectively. The minimal detectable concentrations of insulin, LH and FSH were 0.5, 0.1 and 0.5 ng/mL, respectively.

**Colostrum and milk composition**

Colostrum and milk were collected (30 mL) just after the birth of the first piglet and 10 days after farrowing respectively. The samples were analysed for its macronutrient, total solid, fat, protein, lactose composition and IgG. Nutritional composition (Total solid, fat, protein, and lactose content) was estimated by Milko-Scan 133B (Type 10911) within 24 h. IgG content (mg/mL) was measured by Procine IgG ELISA Kit (E101-104; Belthyl Lab., USA).

![Figure 2](image-url)  
*Figure 2.* The maximum and minimum temperature during the experiment.
Statistical analyses

Data generated in the present experiment was analysed as a $2 \times 2$ factorial arrangement in a completely randomised design. Data were replicated over time, whereas the feeder type and back fat thickness were the fixed effect. Sow was considered the experimental unit. The main effects of feeder type, backfat thickness during farrowing to weanling and their interaction were determined by mixed procedure of SAS statistical programme (SAS Inst., Inc., Cary, NC, USA). A $p \leq 0.05$ were considered statistically significant. The data were tested for main effects of feeder type, back fat and their possible interaction. The following model statement was used:

$$Y_{ijt} = \mu + \alpha_i + \beta_j + \gamma_{t} + \alpha\beta_{ij} + \epsilon_{ijt}$$

where $Y_{ijt}$ = measured response, $\mu$ = overall mean, $\alpha_i$ = feeder type, $\beta_j$ = back fat effect, $\gamma_{t}$ = the fixed time effect when the measurement was taken, $\alpha\beta_{ij}$ = interaction between feeder type and back fat effect, and $\epsilon_{ijt}$ = residual error.

In microbial and VFA samples, statistical analysis was analysed as repeated measures using MIXED procedure of SAS (SAS Institute Inc., Cary, NC, USA). Orthogonal polynomial contrasts were used to evaluate linear and quadratic effects of fermentation in hot environment. To test the hypotheses, $p < 0.05$ was considered significant.

Results

Backfat thickness, feed intake, feeding pattern and weaning-to-oestrus interval

The body weight, backfat thickness, and weaning-to-oestrus interval of lactating sows are shown in Table 1. There was no feeder type $\times$ backfat thickness interaction for any measured variables. Feeder type and backfat thickness had significant effects ($p < 0.05$) on body weight changes during lactation. At the end of gestation and at weaning, sows in both thin backfat (<20 mm) and FFT groups showed lower backfat changes and greater feed intake. The result of the current study showed that there are two peaks of feeding activity in FFT sows. According to Figure 3, from the comparison of the hourly feed intakes (between 0000 and 2400), the pattern of feed intake in sows peaked

| Table 1. Effects of free feeding time (FFT) and backfat thickness on backfat thickness (BF) changes, feed intake and weaning to oestrus interval in sows during summer season. |
|---------------------------------|
| Item                      | Control | FFT  |
|---------------------------|---------|------|
| Parity                    | 3.43    | 3.31 |
| Sow body weight, kg       | 228.8   | 220.4|
| Gestation, d109           | 207.7   | 203.4|
| Weaning                   | 21.16   | 17.02|
| Sow backfat thickness, mm | 17.86   | 17.69|
| Gestation, d109           | 14.14   | 14.54|
| Weanling                  | 3.79    | 3.15 |
| Change                    | 5.22    | 4.62 |
| Daily feed intake, kg/d   | 4.79    | 4.62 |
| Weaning to oestrus interval, d | 3.43    | 3.31 |

SEM: standard error of means.

Figure 3. The average hourly feed intake pattern of lactating sows in free feeding time treatment.
twice a day. The first and the second peaks were observed between 0500 and 0700 and between 2000 and 2400, respectively. On average, about 29% and 38% of the meals occurred during the first and the second peaks, respectively.

Neither feeder type nor backfat thickness at lactation had a significant effect ($p < .05$) on weaning-to-oestrus interval for sows.

**Litter performance**

The effect of feeder type and backfat thickness on litter size and piglet performance of sows is shown in Table 2. There was no feeder type × backfat thickness interaction for any of the measured variables. There were no significant effects of feeder type or backfat thickness on initial litter size. There were no effects on litter weight in sows with different backfat thicknesses. However, sows in the FFT group tended to have greater litter weight ($p = .074$) and total weight gain ($p = .063$). Hence, FFT had a significant effect ($p < .05$) on the average daily gain of piglets.

**Microflora and VFA**

The linear relationships between microbial population and feed sampling time from the feeders are given in Table 3. There were linear and quadratic increase in the count of *Lactobacillus* spp. and coliforms over time. The production of acetic acid in the feeder (Table 3) was linearly increased in the feeders over time.

**Blood metabolites**

The effects of feeder type and backfat thickness on blood metabolites are presented in Table 4. There were no significant effects or interaction effects between feeder type and backfat thickness on blood urea nitrogen, glucose, or creatinine levels of weanling and post-farrowing sows during the summer season. However, the concentration of blood triglycerides tended to increase in sows with lower backfat thickness.

**Hormone profiles**

Hormone profiles of sows are shown in Table 5. There were no interaction effects between feeder type and backfat thickness on hormone profiles. There were no effects on the FSH, LH, cortisol, or insulin of post-farrowing and weanling sows during the summer season.

| Table 2. Effects of free feeding time (FFT) and backfat thickness (BF) on litter size and piglet performance in sows during summer season. |
|---------------------------------------------------------------|
| **Item** | **Control**<br>**<20 (n = 14)** | **≥20 (n = 14)** | **FFT**<br>**<20 (n = 13)** | **≥20 (n = 15)** | **SEM** | **FFT**<br>| **BF**<br>| **FFT × BF**<br> |
| Litter size | | | | | | | | |
| Initial litter size | 10.21 | 10.36 | 10.23 | 10.40 | 0.35 | .933 | .659 | .970 |
| Piglets weaned | 10.07 | 10.14 | 10.08 | 10.20 | 0.34 | .929 | .781 | .941 |
| Litter weight, kg | | | | | | | | |
| Initial litter | 13.34 | 13.46 | 13.31 | 13.55 | 0.34 | .921 | .581 | .853 |
| Initial litter, kg/pig | 1.32 | 1.31 | 1.33 | 1.30 | 0.04 | .937 | .603 | .860 |
| Piglets weaned | 69.37 | 68.37 | 72.58 | 71.46 | 1.70 | .074 | .541 | .973 |
| Piglets weaned, kg/pig | 6.96 | 6.77 | 7.31 | 7.03 | 0.17 | .075 | .166 | .790 |
| Total weight gain | 56.03 | 54.91 | 59.27 | 57.90 | 1.60 | .045 | .150 | .769 |
| Average daily gain, g/pig | 224.4 | 217.5 | 238.3 | 227.9 | 5.72 | |

SEM: Standard error of means.

| Table 3. The effect of fermentation on microbial and volatile fatty acid changes of wet feed in hot environment. |
|---------------------------------------------------------------|
| **Item** | **Time**<br>**T1**<br>*VFA*’s, µg/mL | **T2**<br>Acetic acid | **T3**<br>Lactic acid | **T4**<br>Microflora, Log10 CFU/g | **SEM**<br>Lactobacillus spp. | **p Value**<br>Linear | **Quadratic**<br> |
|-------------------------------|-------------------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| VFA’s, µg/mL                   | 5.97                          | 12.19                | 16.11                | 17.48                | 0.29                 | <.001                 | .001                 |
| Acetic acid                    | ND                            | ND                   | ND                   | ND                   | –                    | –                    | –                    |
| Lactic acid                    | ND                            | ND                   | ND                   | ND                   | –                    | –                    | –                    |
| Microflora, Log10 CFU/g        | 3.82                          | 4.01                 | 5.02                 | 5.62                 | 0.07                 | <.001                 | <.001                 |
| Lactobacillus spp.             | 3.41                          | 3.45                 | 3.67                 | 3.91                 | 0.05                 | <.001                 | <.001                 |
| Coliforms                      | 3.41                          | 3.45                 | 3.67                 | 3.91                 | 0.05                 | <.001                 | <.001                 |

SEM: Standard error of means; VFA: volatile fatty acids.

†T1, T2, T3, and T4 represents the time 1, 3, 6, and 8 hours after adding the feed into the conventional feeders respectively.
Colostrum and milk composition data of sows are presented in Table 6. There was no feeder type × backfat thickness interaction for any of the measured variables. Feeder type and backfat thickness had no significant effects on colostrum and milk composition of sows during the summer season.

**Discussion**

In the present study, both body weight change and backfat change were decreased in sows in the FFT group and in sows with lower backfat thickness in hot weather. It is widely recognised that the backfat thickness and body conditions of sows affect the subsequent reproductive performance of sows (Houde et al. 2010; Strathe et al. 2017). Higher variation in feed intake feeding pattern and milk production increases the variation in backfat thickness and losses of backfat levels at weaning (Maes et al. 2004; Strathe et al. 2017). Reasons for the change in sows’ backfat and the weight change during lactation are attributed to feed intake, but they may correlate to temporal patterns of stress, which have been shown to decrease...
the piglet ADG in sows fed in conventional feeders during acute heat stress. According to previous studies, sows mobilise more body energy with increased backfat thickness (Schenkel et al. 2010) and litter size (Neil et al. 1996; Strathe et al. 2017), and in the current study, sows with thicker backfat layers prior to farrowing lost more backfat in hot weather. Therefore, the higher backfat loss was likely associated with the energy required for the increased body metabolism in heavy sows. Previous results suggest that the decrease in feed intake might be explained by the releasing of leptin in adipose cells (Cervantes et al. 2016).

In the present study, there were no effects of backfat thickness or feeder type on weaning-to-oestrus intervals, however, feed intake during lactation was greater in sows with <20 mm backfat thickness. High temperature has significant negative influences on body weight, which could be associated with the restricted feed intake (Silva et al. 2009) and the increased energy requirement needed for the self-thermoregulation of the body (Neil et al. 1996), particularly in heavy sows (>20 mm) in the current study. Regardless of feeder type, a decrease in the feed intake in heavy sows might be one of the physiological mechanisms used by sows to control the heat increment, as Mordenti et al. (2003) also reported that above the comfort temperature the pig reduce feed intake to maintain heat increment equal to the environmental heat demand. It has been suggested that the pattern of voluntary feed intake during lactation might be directly related to the energy requirement for lactation, since milk production accounts as a large proportion of the energy requirement of lactating sows (Strathe et al. 2017). Using nutritional management solutions in the lactation period is one way to decrease heat stress in sows. Therefore, changes in eating and drinking patterns can be helpful to maximise feed intake. Two peaks of feeding activity occur in the morning and in the evening under naturally fluctuating temperatures (Silva et al. 2009). During the current experiment, there were two peaks of feeding activity in sows in FFT treatment under naturally fluctuating temperatures. These results show that not only light intensity changes but also the presence of staff affects the feeding pattern. In the current study, the stufs presented in the room between 2000 and 2100 h and it stimulated sows to receive more feed, following a sharp decrease in feeding at 2200 h. The hourly feed intake values were less between 1000 and 1900 h. It can then be hypothesised that the time between 1000 and 1900 h is the best to avoid feeding sows in hot weather. Reduced subsequent reproductive performance occurs because of either an insufficient amount of body reserves at farrowing or restricted feed intake during lactation. These points collectively show the importance of mobilisable body reserves that can be used during lactation without influencing reproductive performance, such as the weaning-to-oestrus interval (Houde et al. 2010). As shown in this study, the higher body reserves at farrowing reduce voluntary feed intake and increase weight loss during lactation. The thicker backfat in lactating sows is corroborated by eating fewer meals rather than smaller meals, resulting in a total lower feed intake (Weldon et al. 1994). As indicated in the present study, when the weather is hot, spontaneous fermentation of wet feed occur in the feeder if dispensed feed is not immediately consumed, and the composition of residues of feed in the feeder can thus lead to bacterial contamination. The fermentation process is often accompanied by the loss of nutrients (Brooks et al. 2003; Niven et al. 2006; Brooks 2008). Biogenic amines, such as cadaverine, are good examples of irreversible amino acids lost in feed fermentation by coliforms, which are formed from the decarboxylation of synthetic lysine (Brooks et al. 2003; Niven et al. 2006). The palatability of feed may be compromised through the uncontrolled fermentation process due to higher concentrations of ethanol, acetic acid, and biogenic amines (Brooks et al. 2003; Niven et al. 2006). Brooks (2008) reported that feed intake can be adversely affected by the presence of acetic acid, in agreement with the result of current study. It is critical to point out that our study did not subject animals to changed feed intake but rather was initiated to feed sows at an appropriate time during the day. It was assumed that all the sows in the different feeder groups were in the same heat stress conditions and that, thus, their appetites were similar. Therefore, it was assumed that both overweight sows and the change in feed quality due to uncontrolled fermentation in heat stress were the reasons for the lower feed intake.

The weight of weaned piglets was not affected by backfat thickness. However, sows in the FFT group showed a greater average daily gain of piglets. The greater average daily gain of piglets in FFT group may have been due to increased feed intake. The greater feed intake positively affect the energy balance and improve milk production in sows (Strathe et al. 2017). In contrast to the result of the present study, the result of a previous study showed that the level of backfat losses was proportional to the weight of weaned piglets (Maes et al. 2004). Generally, the overall interactions between sows’ feed intake and weight loss during lactation indicates the growth of offspring...
As expected, FFT sows in the current study lost less body weight but showed greater litter growth. The lower negative energy balance during the lactation of sows in the FFT group may have led to greater litter size. On the other hand, sows that had greater backfat also had reduced daily feed intake during lactation, but it had no negative consequences on litter size. The negative effect of lower feed intake was probably offset by the increased body fat mobilisation.

Heat stress causes a decrease in glucose concentrations in pigs mainly due to decreased feed intake (Pearce et al. 2013). However, the result of the current study showed no differences in blood glucose between the FFT and control groups, whereas sows in the FFT group had higher feed intake. Data from Farmer et al. (2007) did not show higher blood glucose concentration in sows were exposed to heat stress. Changes in blood parameters appear to be important factors during heat stress. In contrast to our expectations, blood metabolites did not show any significant differences between groups, whereas the performance and feed intake in sows differed. The only difference found was for a tendency in blood triglycerides; that is, sows with less backfat showed a numerically higher blood triglycerides. In contrast, other research studies have shown that the rate of released fat to the bloodstream is greater when there are greater fat reserves in sows (Eissen et al. 2000). Furthermore, pigs that are affected more by heat stress have lower voluntary feed intake during lactation and increased blood non esterified fatty acids but similar blood triglycerides (Pearce et al. 2013). A greater understanding of how blood metabolites can be affected in heat stress environments is needed, since the result of this study differed from those of previous studies.

The present study showed no difference in total solid, protein, fat, and lactose of milk and colostrum. Milk production did not measure in the present study, however, several studies confirmed that sows with greater feed intake have a greater capacity to produce milk and showing a greater litter weight gain in comparison with sows with low feed intake (Kim et al. 2016; Strathe et al. 2017). Regarding the possible effect of feed intake on sows milk production, the expected result of an improvement in milk composition of sows in FFT treatment may be rejected.

Conclusions

These data present a decrease in body reserves in sows during the period of lactation due to the use of conventional feeders in hot environments. The present study shows that controlling the feeding and releasing the feed into the feeders at the appropriate time during the lactation period decreases uncontrolled fermentation and improves the feed intake of sows subjected to hot ambient temperatures, leading to a greater piglet average daily gain. The greater feed intake in the FFT group influenced litter performance, whereas the backfat thickness of lactating sows at farrowing had no influence on litter performance in hot weather.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

Brooks PH, Beal JD, Niven S, Demeckova V. 2003. Liquid feeding of pigs II. Potential for improving pig health and food safety. Anim Sci Pap Rep. 21:23–39.
Brooks PH. 2008. Fermented liquid feed for pigs. Cab Rev. 3:1–18.
Cervantes M, Cota M, Arce N, Castillo G, Avelar E, Espinoza S, Morales A. 2016. Effect of heat stress on performance and expression of selected amino acid and glucose transporters, HSP90, leptin and ghrelin in growing pigs. J Therm Biol. 59:69–76.
Dourmad JY, Noble JT, Etienne M. 1998. Effect of protein and lysine supply on performance, nitrogen balance, and body composition changes of sows during lactation. J Anim Sci. 76:542–550.
Eissen JJ, Kanis E, Kemp B. 2000. Sow factors affecting voluntary feed intake during lactation. Livest Prod Sci. 64:147–165.
Farmer C, Knight C, Flint D. 2007. Mammary gland involution and endocrine status in sows: Effects of weaning age and lactation heat stress. Can J Anim Sci. 87:35–43.
Houde AA, Methot S, Murphy BD, Bordignon V, Pali MF. 2010. Relationships between backfat thickness and reproductive efficiency of sows: a two-year trial involving two commercial herds fixing backfat thickness at breeding. Can J Anim Sci. 90:429–436.
Kim JS, Hosseindoust A, Lee SH, Choi YH, Noh HS, Chae BJ. 2015. Effect of dry, wet and liquid feeding on the performance, digestibility and carcass characteristics of growing pigs. Ann Anim Resour Sci. 26:101–109.
Kim KH, Hosseindoust A, Ingale SL, Lee SH, Noh HS, Choi YH, Jeon SM, Kim YH, Chae BJ. 2016. Effects of gestational housing on reproductive performance and behavior of sows with different backfat thickness. Asian-Australas J Anim Sci. 29:142–148.

(Strathe et al. 2017).
Kim JS, Hosseindoust A, Ju IK, Yang X, Lee SH, Noh HS, Lee JH, Chae BJ. 2018. Effects of dietary energy levels and β-mannanase supplementation in a high mannan-based diet during lactation on reproductive performance, apparent total tract digestibility and milk composition in multiparous sows. Ital J Anim Sci. 17:128–134.

Mordenti A, Bosi P, Corino C, Crovetto GM, Casa GD, Franci O, Piva A, Prandini A, Russo V, Schiavon S. 2003. Nutrient requirements of heavy pig. Ital J Anim Sci. 2:73–87.

Maes DGD, Janssens GPJ, Delputte P, Lammertyn A, de Kruif A. 2004. Back fat measurements in sows from three commercial pig herds. I. Relationship with reproductive efficiency and correlation with visual body condition scores. Livest Prod Sci. 91:57–67.

Neil M, Ogle B, Anner K. 1996. A two-diet system and ad libitum lactation feeding of the sow. 1. Sow performance. J Anim Sci. 62:337–347.

Niven SJ, Beal JD, Brooks PH. 2006. The effect of controlled fermentation on the fate of synthetic lysine in liquid diets for pigs. Anim Feed Sci Technol. 129:304–315.

[NRC] National Research Council. 2012. Nutrient Requirements of Swine. 11th ed. Washington (DC): Natl. Acad. Press.

Pearce SC, Gabler NK, Ross JW, Escobar J, Patience JF, Rhoads RP, Baumgard LH. 2013. The effects of heat stress and plane of nutrition on metabolism in growing pigs. J Anim Sci. 91:2108–2118.

Porter MG, Murray RS. 2001. The volatility of components of grass silage on oven drying and the inter-relationship between dry-matter content estimated by different analytical methods. Grass Forage Sci. 56:405–411.

Quiniou N, Noblet J. 1999. Influence of high ambient temperatures on performance of multiparous lactating sows. J Anim Sci. 77:2124–2134.

Schenkel AC, Bernardi ML, Bortolozzo FP, Wentz I. 2010. Body reserve mobilization during lactation in first parity sows and its effect on second litter size. Livest Sci. 132:165–172.

Silva BAN, Oliveira RFM, Donzele JL. 2009. Effect of floor cooling and dietary amino acids content on performance and behaviour of lactating primiparous sows during summer. Livest Sci. 120:25–34.

Strathe AV, Bruun TS, Hansen CF. 2017. Sows with high milk production had both a high feed intake and high body mobilization. Animal. 11:1913–1921.

Weldon WC, Lewis AJ, Louis GF, Kovar JL, Giesemann MA, Miller PS. 1994. Postpartum hypophagia in primiparous sows. I. Effects of gestation feeding level on feed intake, feeding behavior and plasma metabolite concentrations during lactation. J Anim Sci. 72:387–394.

Yang Y, Galle S, Le MHA, Zijlstra RT, Gänzle MG. 2015. Feed fermentation with reuteran-and levan-producing Lactobacillus reuteri reduces colonization of weanling pigs by enterotoxigenic Escherichia coli. Appl Environ Microbiol. 81:5743–5752.