Effects of dietary energy levels and \( \beta \)-mnnanase supplementation in a high mannan-based diet during lactation on reproductive performance, apparent total tract digestibility and milk composition in multiparous sows

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\textbf{ABSTRACT}

Two experiments were conducted to investigate the effects of dietary supplementation of \( \beta \)-mnnanase and energy level on reproductive performance of multiparous sows during lactation. In Exp. 1, 30 multiparous sows were randomly allotted to three treatments (0400 and 800 units \( \beta \)-mnnanase). In Exp. 2, 60 multiparous sows were fed diets containing 3250 or 3350 kcal ME/kg diet and 0 or 400 units of \( \beta \)-mnnanase in a 2\( \times \)2 factorial arrangement. A linear reduction in sow body weight (BW) loss during lactation was observed with increasing levels of \( \beta \)-mnnanase. The BW change during lactation was significantly lower in sows fed high-energy diets or dietary \( \beta \)-mnnanase. \( \beta \)-mnnanase supplementation increased the apparent total tract digestibility of dry matter, gross energy and mannose. Diets supplemented with \( \beta \)-mnnanase or high-energy diet increased milk fat level. Furthermore, high-energy diet increased lactose level in milk. Collectively, our data indicate that dietary inclusion of \( \beta \)-mnnanase has the potential to improve digestibility of nutrients and reduce sow BW loss during lactation.

\textbf{Introduction}

During lactation, sow feed intake is not sufficient to meet the nutrient requirements for maintenance, foetal growth and lactation, which leads to mobilisation of body reserves (Imaeda and Yoshioka 2007; Lawlor and Lynch 2007). It has been reported that excessive loss of body protein and backfat during gestation and lactation is associated with an increased percentage of stillborn piglets (Maes et al. 2004), and a decreased litter growth (Clowes et al. 2003), prolonged weaning-to-oestrus interval, reduced pregnancy rate and shorter sow productive lifetime (De Rensis et al. 2005; Serenius et al. 2006). Increasing the feed intake of lactating sows reduces the loss of backfat depth and body weight (BW), and increases the litter weight gain (Eissen et al. 2003). Therefore, increasing the nutrient density of the diet to reduce the extent of backfat and BW losses, while also enhancing the growth rate and weight gain of progeny, is common practice in the sow industry.

Palm kernel meal, rapeseed meal and distiller dried grains have attracted considerable attention as animal feed due to their similar nutritional value and low cost compared to soybean meal (SBM) and corn (Seo et al. 2015; Kim, Ingale et al. 2016). However, these feeds are rich in non-starch polysaccharides (NSP) such as \( \beta \)-mnnan which restricts their use in swine diets because pigs do not secrete the necessary enzymes required to hydrolyse NSP (Ao et al. 2011). The \( \beta \)-mnnan accounts for 15–37\% (for soybean to palm) of the total NSP content of pig diets (CVB 1998). Consequently, supplementation of NSP-hydrolysing enzymes has been shown to increase the nutrient digestibility of pig diets (Jo et al. 2012; Walsh et al. 2012; Kim et al. 2013). Walsh et al. (2012) reported that dietary supplementation of NSP-hydrolysing enzymes increased energy intake before farrowing, during lactation and in the period between weaning and reservice. According to Lee et al. (2011), the feed conversion ratio was improved by adding an enzyme...
premix containing mannanase to pigs diet during the finishing period. Although supplementation with exogenous enzymes increased the digestibility of nutrients during lactation in sows, a similar response was not seen during gestation (De Souza et al. 2007). However, the beneficial effects of exogenous enzyme supplementation depend on the substrate type, physiological status of the pigs and the NSP content in the diet (Adeola and Cowieson 2011; Lee et al. 2011). Therefore, supplementing exogenous enzymes on the basis of type and content of NSP in pig diets is essential to attain the potential benefits. Therefore, the objectives of the present experiments aimed to investigate the effects of dietary supplementation of β-mannanase during lactation on the reproductive performance and the colostrum and milk composition of multiparous sows.

Materials and methods

Animals and management

All sows used in this study were artificially inseminated 2 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). During gestation, all sows were housed in individual gestation stalls (2.05 × 1.08 m) with fully slatted concrete flooring. All sows were moved to farrowing crates (2.14 × 2.15 m) on d 109 of gestation. Each crate had a single feeder, and sows were moved to farrowing crates (2.14 × 2.15 m) on d 109 of gestation. Each crate had a single feeder, and water was always available through a nipple drinker. The farrowing room temperature was maintained at 20 °C before farrowing, increased to 24 °C for the first 2 week of lactation and subsequently lowered to 20 °C. Heating pads for piglets were located on either side of the farrowing crates and maintained at 36 °C. Sows had ad libitum access to water via a drinker located in the feed trough in each farrowing crate. The feeders were checked 3 times per day to be refilled when required.

In Exp. 1, 30 multiparous crossbred sows (Landrace × Yorkshire; average initial BW, 237.7 kg) were allotted to four treatments. Sows were fed diets containing 3300 or 3350 kcal/kg diet ME and 0 or 400 U/kg of β-mannanase. In both experiments, starting from the day after farrowing, the ration was gradually increased by one kg per day until maximum ration was reached (2 kg + 0.6 kg per piglet) about seven days post-partum. Unconsumed feed was weighed daily to determine actual feed intake. All the sows were fed a common corn-soybean meal base diet as per NRC (1998) requirements for lactation (Table 1).

Measurements and data collection

Live weight was measured on d 109 (prefarrowing) during gestation and d 24 (weaning) during lactation. Sow backfat thickness at the 10th rib was recorded at d 109 of gestation, and at weaning (d 24 ± 1 of lactation)

### Table 1. Ingredient and nutrient compositions of sow lactation diets (g/kg, as fed).

| Item | Exp. 1          | Exp. 2          | Low nutrient density | High nutrient density |
|------|-----------------|-----------------|----------------------|-----------------------|
| Corn | 410.0           | 393.4           | 410.0                |
| Wheat| 100.0           | 100.0           | 100.0                |
| Palm kennel meal | 20.0 | 20.0 | 20.0 |
| DDGS | 80.0            | 80.0            | 80.0                 |
| Soybean meal (Local) | 228.3 | 219.6 | 228.3 |
| Soybean meal | 58.8            | 72.9            | 58.8                 |
| Animal fat | 40.3           | 35.0            | 40.3                 |
| Molasses | 30.0            | 40.0            | 30.0                 |
| Glucose | 61.0            | 58.0            | 61.0                 |
| Galactose | 20.0            | 18.0            | 20.0                 |
| Methionine | 0.4          | 0.5             | 0.4                  |
| Lysine | 11.5            | 11.5            | 11.5                 |
| Methionine + Cysteine | 7.2 | 7.2 | 7.2 |
| Salt | 5.0             | 8.7             | 5.0                  |
| Vitamin premix | 1.6           | 1.6             | 1.6                  |
| Mineral premix | 1.0           | 1.0             | 1.0                  |
| Phytase | 0.3             | 0.3             | 0.3                  |
| Calculated composition, ME, MJ/kg | 14,016 | 13,807 | 14,016 |
| Crude protein | 201.3           | 201.3           | 201.3                |
| Protein | 201.3           | 201.3           | 201.3                |
| Lysine | 11.5            | 11.5            | 11.5                 |
| Methionine + Cysteine | 7.2 | 7.2 | 7.2 |

Exp. 1: Low nutrient density; Exp. 2: High nutrient density

#### Notes

*Supplied per kg diet: 9600 U vitamin A, 1800 U vitamin D₃, 24 mg vitamin E, 1.5 mg vitamin B₁₂, 12 mg vitamin B₁, 2.4 mg vitamin B₂, 0.045mg vitamin B₆, 1.5 mg vitamin K₃, 24 mg pantothenic acid, 45 mg niacin, 0.09 mg biotin, 0.39 mg folic acid, 7.2 mg ethoxyquin.

*Supplied per kg diet: 150 mg Fe, 96 mg Cu, 72 mg Zn, 46.5 mg Mn, 0.9 mg I, 0.9 mg Co, 0.3 mg Se.
using an ultrasonic device (Agroscan A16, France). Changes in backfat thickness of sows during lactation were estimated by calculating the difference between backfat thicknesses at d 109 of gestation and backfat thickness at d 24 of lactation. Standard litter traits such as number born and born alive, body weight (kg) at birth and weaning, and numbers weaned were recorded. Feed intake (kg/d) of each sow and weaning-to-oestrus interval (d) were also recorded. The value of the average daily gain (ADG) of piglets was calculated by final body weight minus the first body weight divided by weaning date (day) multiplied by the number of weaned piglets.

To evaluate the effects of dietary treatments on the apparent total tract digestibility (ATTD) of energy and nutrients, 0.25% chromic oxide (an inert indigestible indicator) was included in each diet from d 14 to 24 of lactation. Faecal grab samples were collected from the floor of each pen during last 4 days of each experiment to determine the ATTD of dry matter (DM), gross energy (GE) and crude protein (CP). The faecal samples were pooled within pen and dried in a forced air dry-oven at 60°C for 72 h, and ground in a Wiley mill (Thomas Model 4 Wiley Mill, Thomas Scientific, Swedesboro, NJ) using a 1-mm screen and used for chemical analysis. The content of arabinose, xylose, mannose, galactose and glucose in feed ingredients, diets and excreta samples was evaluated according to the method of Englyst and Cummings (1984). Experimental diets and excreta samples were analysed in triplicate for DM (Method 930.15) and CP (Method 990.03) according to AOAC (2007) methods. Gross energy of diets and faeces was measured by a bomb calorimeter (Model 1261, Parr Instrument Co., Moline, IL), and chromium concentrations were determined with an automated spectrophotometer (Jasco V-650, Jasco Corp., Tokyo, Japan) according to the procedure of Fenton and Fenton (1979).

Approximately 25 ml of colostrum and milk samples were separated and stored at −20°C and later analysed for blood metabolites (triacylglycerides, BUN and glucose) and insulin. Commercial kits (Fujifilm Corp., Saitama, Japan) were used for analysis of blood metabolites using an automated chemistry analyser (Fuji Dri-Chem 3500i, Fujifilm Corp.).

**Statistical analyses**

In Exp. 1, statistical analysis was conducted using the GLM procedure (SAS Inst. Inc. Cary, NC). The linear and quadratic contrasts were used to compare the effect of dietary β-mannanase level (0, 400 and 800 U/kg). Individual sow was used as experimental unit for analysis of all variables. In Exp. 2, data were analysed as a 2 × 2 factorial arrangement of treatments in randomized blocks. The main effects of dietary energy level, β-mannanase and their interaction were determined by the MIXED procedure of SAS. Probability values of ≤.05 were considered significant in both experiments.

**Results**

**Sow and litter performance**

The effects of β-mannanase supplementation on sow reproductive performance are shown in Tables 2 (Exp. 1) and 3 (Exp. 2). In Exp. 1, increasing the level of β-mannanase supplementation reduced the loss of sow BW during lactation (linear, p < .05). In contrast, dietary treatment had no effects on backfat thickness, feed intake and wean-to-oestrus interval of the sows. Similarly, litter size and weight at birth and weaning were not affected by dietary treatment.

In Exp. 2, no interaction between energy and β-mannanase was observed for any of the parameters measured. However, increasing the dietary energy and β-mannanase supplementation significantly reduced (p < .05) the sow BW loss during lactation. However, dietary energy levels and β-mannanase supplementation had no influence on sow backfat thickness during lactation, litter size and weight at birth, and weaning (Table 3).

**Blood metabolites**

Increasing the dietary levels of β-mannanase had no effects (p > .05) on the blood metabolites (triacylglycerides, glucose, BUN and insulin) at post-farrowing and weaning (Table 4).

**Nutrient digestibility**

No interactions were observed between the energy level of the diet and β-mannanase.
supplementation (Table 5). In Exp. 2, the ATTD of DM, GE, CP, xylose, mannose, galactose and glucose was not affected by the dietary energy levels. However, the arabinose digestibility tended (\( p = .06 \)) to be greater in high-energy diets. Sows fed the diets supplemented with β-mannanase had a greater (\( p < .05 \)) ATTD of DM, GE and mannose. Furthermore, dietary β-mannanase tended to improve the digestibility of galactose (\( p = .06 \)).

**Colostrum and milk composition**

In Exp. 2, sows fed high-energy diets produced milk with higher fat and lactose contents than those fed

### Table 2. Effects of β-mannanase supplementation on reproductive performance of multiparous sows (Exp. 1).

| Item                                | 0            | 0.05         | 0.1          | SEM | Linear | Quadratic |
|-------------------------------------|--------------|--------------|--------------|-----|--------|-----------|
| Body weight, kg                     | 239.7        | 241.8        | 237.4        | 2.98| .590   | .381      |
| D 109 of gestation                  | 223.6        | 227.2        | 225.3        | 3.05| .697   | .468      |
| At weaning                          | 16.10        | 14.60        | 12.10        | 1.13| .019   | .721      |
| Change during lactation (→)         | 16.10        | 14.60        | 12.10        | 1.13| .019   | .721      |
| Backfat thickness, mm               | 18.70        | 18.95        | 18.85        | 0.47| .825   | .766      |
| D 109 of gestation                  | 15.40        | 15.80        | 16.30        | 0.46| .174   | .929      |
| At weaning                          | 2.90         | 2.65         | 2.55         | 0.26| .157   | .618      |
| Change during lactation (→)         | 5.83         | 5.78         | 6.04         | 0.31| .638   | .681      |
| Feed intake, kg/d                   | 5.40         | 5.10         | 5.20         | 0.41| .326   | .807      |
| Wean-to-oestrus interval, d         | 12.90        | 12.60        | 12.70        | 0.48| .773   | .739      |
| Piglet performance                  | 10.60        | 10.47        | 10.53        | 0.25| .794   | .601      |
| Numbers weaned                      | 15.42        | 16.16        | 14.56        | 0.82| .466   | .259      |
| Birth weight, kg                    | 75.54        | 77.02        | 76.84        | 1.97| .643   | .735      |

SEM: standard error of the mean.

### Table 3. Effects of dietary energy levels and β-mannanase supplementation on reproductive performance of multiparous sows (Exp. 2).

| ME, kcal/kg | 3300 | 3350 | p-values |
|-------------|------|------|----------|
| β-mannanase |      |      |          |
| Item        | 0    | 400  | 800      | SEM | Linear | Quadratic |
| Body weight, kg | 258.5 | 257.2 | 258.2 | 257.0 | 3.08 | .923 | .614 | .986 |
| D 109 of gestation | 232.0 | 234.2 | 236.6 | 238.2 | 3.25 | .113 | .488 | .903 |
| At weaning | 26.44 | 22.94 | 21.55 | 18.79 | 1.71 | .002 | .029 | .792 |
| Change during lactation (→) | 18.87 | 18.41 | 18.61 | 18.48 | 0.39 | .764 | .348 | .610 |
| Backfat thickness, mm | 16.00 | 15.88 | 16.14 | 16.27 | 0.51 | .526 | .999 | .762 |
| D 109 of gestation | 2.87 | 2.53 | 2.47 | 2.21 | 0.36 | .229 | .321 | .908 |
| At weaning | 4.67 | 4.53 | 4.60 | 4.27 | 0.38 | .590 | .452 | .747 |
| Change during lactation (→) | 5.00 | 4.13 | 4.53 | 4.27 | 0.30 | .578 | .062 | .318 |
| Feed intake, kg/d | 10.73 | 10.47 | 10.53 | 10.50 | 0.25 | .794 | .601 | .601 |
| Wean-to-oestrus interval, d | 10.40 | 10.13 | 10.27 | 10.10 | 0.21 | .749 | .338 | .749 |
| Piglet performance | 14.47 | 14.14 | 14.30 | 14.29 | 0.27 | .960 | .519 | .552 |
| Numbers born litter | 76.20 | 75.67 | 76.25 | 76.21 | 1.42 | .838 | .841 | .866 |

SEM: standard error of the mean; ME: energy level; E: enzyme (β-mannanase).

### Table 4. Effects of β-mannanase supplementation on blood profiles of sows during gestation and lactation.

| Item                                | β-mannanase (U) | p-value |
|-------------------------------------|-----------------|---------|
|                                  | 0    | 400  | 800  | SEM | Linear | Quadratic |
| Post-farrowing, day 1              |      |      |      |     |        |          |
| Triacylglycerides, mg/dl           | 54.18| 50.96| 52.94| 1.45| .556   | .080      |
| Glucose, mg/dl                     | 88.28| 89.71| 87.74| 2.19| .865   | .539      |
| Blood urea nitrogen, mg/dl         | 15.25| 15.42| 16.03| 0.87| .537   | .841      |
| Insulin, μU/ mL                    | 26.39| 25.78| 22.47| 0.99| .817   | .716      |
|                                   |      |      |      |     |        |          |
| Weaning                           |      |      |      |     |        |          |
| Triacylglycerides, mg/dl           | 25.11| 26.80| 27.82| 0.99| .077   | .789      |
| Glucose, mg/dl                     | 84.25| 83.04| 83.89| 0.83| .769   | .332      |
| Blood urea nitrogen, mg/dl         | 17.91| 18.21| 17.11| 0.57| .341   | .334      |
| Insulin, μU/ mL                    | 15.27| 16.95| 15.56| 1.08| .853   | .269      |
low-energy diets ($p < .05$). Also, β-mannanase supplementation significantly increased ($p < .05$) lactose in milk. However, there was no interaction ($p > .05$) between the diet energy level and β-mannanase on the colostrum and milk compositions (Table 6).

### Discussion

NSP are poorly digested by pigs because they lack the enzymes necessary to degrade the non-starch fibre (Bach-Knudsen and Jorgensen 2001). The current findings indicate that lactating sows fed a high-energy level diet or β-mannanase-supplemented diet, decreases the BW loss during lactation. By targeting the degradation of dietary mannans, it is likely the DM digestibility and nutrient utilisation increased, providing the sows with more energy. Many NSP can decrease nutrient digestibility by encapsulating starch and proteins and increasing the viscosity of the digesta (Kim et al. 2005). As reported in several previous studies, the addition of exogenous enzymes to pig diets may facilitate the hydrolysis of the NSP present in the feed, thus increasing the nutrient utilisation, digestibility and growth performance in pigs (Kiarie et al. 2010; Jo et al. 2012; Walsh et al. 2012). A recent study in the authors’ laboratory revealed that dietary inclusion of β-mannanase may provide the equivalent of 0.36 MJ/kg of ME to growing pig diets (Kim et al. 2013). The present study demonstrated β-mannanase has the potential to increase the utilisation of NSP and, consequently, increase the nutrient utilisation and energy content of the feed for lactating sows. Excessive mobilisation of body fat is a common occurrence in lactating sows and is primarily driven by suboptimum feed intake and increased energy demand to support milk production (Lawlor and Lynch 2007). Increasing feed intake of lactating sows reduces both the losses of backfat depth and BW and also increases litter weight gain (Eissen et al. 2003). A common practice to increase energy intake during lactation is to increase the energy density of the diet (O’Grady and Lynch 1978). Furthermore, the increase in nutrient utilisation by dietary supplementation with exogenous enzymes can improve the performance of pigs (Kim et al. 2013). In the present study, dietary supplementation of β-mannanase offered benefits for sows’ BW loss during lactation. In contrast to the present results, Walsh et al. (2012) observed an increase in feed intake and greater backfat thickness in sows receiving exogenous enzyme during gestation and lactation. Thus, the conflicting findings on the effects of exogenous enzyme supplementation found between this study and the current study might be due to differences in the type and dose of exogenous enzyme and the NSP content of the diets studied.

In the present study, dietary inclusion of β-mannanase had no effects on feed intake during lactation and weaning-to-oestrus interval.
the weaning-to-oestrus interval of sows that received β-mannanase tended to decrease, indicating that the increased dietary energy provided by β-mannanase was insufficient to exert a significant difference. The weaning-to-oestrus interval is often associated with a loss of BW and condition during lactation and the weaning-to-oestrus interval can be reduced by increasing the feed intake during lactation (Kim, Hosseindoust et al. 2016). The absence of effects on the weaning-to-oestrus interval in the present study might be due to a similar feed intake of lactating sows fed the diet with or without β-mannanase. Recently, Walsh et al. (2012) observed an increased feed intake of lactating sows by dietary inclusion of an exogenous enzyme complex but no effects on weaning-to-oestrus interval of sows. In contrast to Walsh et al. (2012) and the present experiment, Ji and Kim (2004) observed a reduced weaning-to-oestrus interval of sows fed diets supplemented with a mixture of carbohydrases.

In the present study, dietary treatments had no effects on litter size and weight at birth and weaning. Similarly, Walsh et al. (2012) observed a dietary exogenous enzyme complex had no effects on the number of born alive, dead, birth weight, numbers of piglets weaned, weaning weight and ADG of piglets. Again, this might be due to a similar feed intake and body condition of the lactating sows fed diets with or without exogenous enzymes. Ji and Kim (2004) observed that supplementing the diet with a carbohydrase mixture during the first lactation improved the reproductive performance of sows by reducing BW loss and days of weaning-to-oestrus; however, this improvement was not successfully carried over to the subsequent parity.

Increasing the levels of supplementary β-mannanase had no effects on blood triacylglycerides, glucose, BUN and insulin during gestation and lactation, and is in agreement with previous studies (Jo et al. 2012; Kim et al. 2013), where no effects of β-mannanase on blood triacylglycerides, glucose and BUN were observed. In contrast to the present results, however, Yoon et al. (2010) observed an increased blood glucose concentration in growing pigs fed a diet supplemented with β-mannanase. These discrepancies in results might be due to variations in the stage of growth and the diet types.

In the present study, dietary inclusion of β-mannanase in the sow diet increased the DM digestibility and energy during lactation. Our results concur with data reported by De Souza et al. (2007), who observed an increase in ileal and total tract digestibility of DM and CP during lactation but no effects on ileal and total tract digestibility of nutrients during gestation. The high intestinal viscosity of mannans has been previously shown to have negative effects on nutrient utilisation (Kim et al. 2005). The main influence of β-mannanase enzyme is due to mannan hydrolysis, which can increase the cell wall permeability and degrade the long-chain polysaccharides to improve the digestibility of nutrients. Mannans are able to trap the nutrients in their complex structure, subsequently interfering with their absorption in the gastrointestinal tract because of their viscous property.

The composition of sow milk was influenced by both the dietary energy content and β-mannanase. Sows fed a high-energy diet had higher concentrations of fat and lactose in milk compared with sows fed a low-energy diet, which is probably due to differences in the fat content of the two diets. In a previous study, Drochner (1989) reported a linear relationship between dietary fat content and milk fat concentration. Similar results were also reported by Yang et al. (2008), who found that high-energy diets led to a greater fat content in milk. The increased milk fat content observed with β-mannanase supplementation may be partly due to the improved digestibility of DM and energy utilisation.

In contrast to the current study, Skrzypczak et al. (2015) reported that differences in the levels of fat and fatty acids found in sows’ colostrum and milk influenced piglet rearing.

Conclusions

Our data indicate that dietary inclusion of β-mannanase has the potential to improve nutrient digestibility and reduce BW loss during lactation, but had no effects on litter performance and compositions of colostrum and milk.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Adeola O, Cowieson AJ. 2011. Board-invited review: opportunities and challenges in using exogenous enzymes to improve non-ruminant animal production. J Anim Sci. 89:3189–3218.
Ao X, Zhou TX, Meng QW, Lee JH, Jang HD, Cho JH, Kim IH. 2011. Effects of a carbohydrase cocktail supplementation on the growth performance, nutrient digestibility, blood profiles and meat quality in finishing pigs fed palm kernel meal. Livest Sci. 137:238–243.
AOAC. 2007. Official methods of analysis. 18th ed. Gaithersburg (MD): Association of Official Analytical Chemists International.
Bach-Knudsen KE, Jorgensen H. 2001. Intestinal degradation of dietary carbohydrates from birth to maturity. In: Lindberg LE, Ogle B, editors. Digestive physiology of pigs. Wallingford (UK): CAB International Publishing; p. 109–121.

Clowes EJ, Ahene FX, Schaefer AL, Foxcroft GR, Baracos VE. 2003. Parturition body size and body protein loss during lactation influence performance during lactation and ovarian function at weaning in first-parity sows. J Anim Sci. 81:1517–1528.

[CVB] Centraal Veevoeder Bureaux. 1998. Veevoedertable (Feeding value of feed ingredients). CVB, Runderweg 6, Lelystad, The Netherlands.

De Rensis F, Gherpelli M, Superchi P, Kirkwood RN. 2005. Relationships between backfat depth and plasma leptin during lactation and sow reproductive performance after weaning. Anim Rep Sci. 90:95–100.

De Souza ALP, Lindemann MD, Cromwell GL. 2007. Supplementation of dietary enzymes has varying effects on apparent protein and amino acid digestibility in reproducing sows. Livest Sci. 109:122–124.

Drochner W. 1989. Einfluss von Fettzulagen an Sauen auf Aufzuchtleistung und Fruchtbarkeit. Übersicht Tierernährung. 17:99–138.

Eissen JJ, Apeldoorn Ej, Kanis E, Verstegen MWA, de Greef KH. 2003. The importance of a high feed intake during lactation of primiparous sows nursing large litters. J Anim Sci. 81:594–603.

Englyst HN, Cummings JH. 1984. Simplified method for the measurement of total non-starch polysaccharides by gas-liquid chromatography of constituent sugars as alditol acetates. Analyst. 109:937–942.

Fenton TW, Fenton M. 1979. An improved method for chromic oxide determination in feed and feces. Can J Anim Sci. 59:631–634.

Imaeda N, Yoshioka G. 2007. Season-dependent effect of daily frequency of feed distribution on the rate of feed consumption and reproductive performance in sows during lactation. Anim Sci J. 78:560–565.

Ji F, Kim SW. 2004. Effects of Carbohydrase supplement on lactation performance of primiparous sows fed corn-soybean meal based lactation diet. Asian Australas J Anim Sci. 17:533–537.

Jo JK, Ingale SL, Kim JS, Kim YW, Kim KH, Lohakare JD, Lee JH, Chae BJ. 2012. Effects of exogenous enzyme supplementation to corn-soybean based or complex diets on growth performance, nutrient digestibility and blood metabolites in growing pigs. J Anim Sci. 89:1795–1804.

Kiarie EG, Slominski BA, Nyachoti CM. 2010. Effect of products derived from hydrolysis of wheat and flaxseed non starch polysaccharides by carboxydrlyze enzymes on net absorption in enterotoxigenic Escherichia coli (K88) challenged piglet jejunal segments. Anim Sci. J. 81:63–71.

Kim JC, Simmins PH, Mullan BP, Pluske JR. 2005. The digestible energy value of wheat for pigs, with special reference to the post-weaned animal: a review. Anim Feed Sci Tech. 122:257–287.

Kim JS, Ingale SL, Lee SH, Kim KH, Kim JS, Lee JH, Chae BJ. 2013. Effects of energy levels of diet and β-mannanase supplementation on growth performance, apparent total tract digestibility and blood metabolites in growing pigs. Anim Feed Sci Tech. 186:64–70.

Kim JS, Ingale SL, Hosseindoust AR, Lee SH, Lee JH, Chae BJ. 2016. Effects of mannannase and β-mannanase supplementation on growth performance, apparent total tract digestibility and blood metabolites of growing pigs. Animal. 14:1–7.

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.

Lawlor PG, Lynch BP. 2007. A review of factors influencing litter size in Irish sows. Ir Vet J. 60:359–366.

Lee SD, Jung HJ, Cho KH, Park JC, Kim IC, Seong PN, Song YM. 2011. Effects of corn dried distiller's grains with solubles and enzyme premix supplements on growth performance, carcass characteristics and meat quality parameters in finishing pigs. Anim Sci J. 82:461–467.

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

NRC. 1998. Nutrient requirements of swine. 10th rev. ed. Washington (DC): National Academy Press.

O'Grady JF, Lynch PB. 1978. Voluntary feed intake by lactating sows: influence of system of feeding and nutrient density of the diet. Irish J Agr Res. 17:1–5.

Seo J, Kim W, Kim J, Kim JK, Kim SC, Yang J, Yang K, Kim K, Kim B, Park S, et al. 2015. Effects of palm kernel expellers on growth performance, nutrient digestibility, and blood profiles of weaned pigs. Asian-australas J Anim Sci. 28:987–992.

Serenius T, Stalder KJ, Baas TJ, Mabry JW, Goodwin RN, Johnson RK, Robinson OW, Tokach M, Miller RK. 2006. National pork producers’ council maternal line national genetic evaluation Program: a comparison of sow longevity and trait associations with sow longevity. J Anim Sci. 84:2590–2595.

Skrzypczak E, Wasiakiewicz A, Beszterda M, Goliński P, Szulc K, Buczynski JT, Babicz M. 2015. Impact of fat and selected profiles of fatty acids contained in the colostrum and milk of sows of native breeds on piglet rearing. Anim Sci J. 86:83–91.

Walsh MC, Geraert PA, Maillard R, Kluss J, Lawlor PG. 2012. The effect of a non-starch polysaccharide-hydrolysing enzyme (Rovabio® Excel) on feed intake and body condition of sows during lactation and on progeny growth performance. Animal. 6:2627–2633.

Yang Y, Heo S, Jin Z, Yun J, Shinde P, Choi J, Yang B, Chae B. 2008. Effects of dietary energy and lysine intake during late gestation and lactation on blood metabolites, hormones, milk composition and reproductive performance in multiparous sows. Arch Anim Nutr. 62:10–21.

Yoon SY, Yang YX, Shinde PL, Choi JY, Kim JS, Kim YW, Yun K, Jo JK, Lee JH, Ohh SJ, et al. 2010. Effects of mannanase and distillers dried grain with solubles on growth performance, nutrient digestibility, and carcass characteristics of grower-finisher pigs. J Anim Sci. 88:181–191.