Effects of supplementing sow diets with fermented corn and soybean meal mixed feed during lactation on the performance of sows and progeny

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ABSTRACT: In the present study, two experiments were performed to study the effects of feeding fermented corn and soybean meal mixed feed (**FMF**) with *Bacillus subtilis* and *Enterococcus faecium* to lactating sows on the performance of the sows and their progeny. In experiment 1, 60 sows were allocated to the following three dietary treatments: 1) sows fed a corn and soybean meal basal diet (control) from day 3 before parturition to weaning, 2) sows fed a diet with 7.5% FMF, and 3) sows fed a diet with 15% FMF. Results indicated that feeding 15% FMF significantly improved ($P < 0.05$) the sows' ADFI, the individual piglet weaning weights, and piglet weight gain and reduced ($P < 0.05$) the backfat loss of sows compared with the control group. However, the 7.5% FMF treatment did not alter the performance of the sows or their progeny. Therefore, we considered the level of 15% FMF to be more efficient than 7.5% FMF. To verify the results of experiment 1, we performed experiment 2, in which 60 sows at 111 d of gestation were allocated into the following two dietary treatments: 1) sows fed a basal lactation diet (control) from d 111 of gestation to weaning and 2) sows fed a basal diet with 15% FMF. Compared with the control group, 15% FMF inclusion significantly increased ($P < 0.05$) the sows' ADFI, litter weight gain, and individual piglet weight gain during lactation and markedly decreased the backfat loss of sows ($P < 0.05$) and piglet diarrhea incidence ($P < 0.05$). Additionally, the milk yield and IgA contents of the milk in sows fed 15% FMF were greater ($P < 0.05$) than those of the control group. Furthermore, the apparent total tract digestibility of GE, DM, and total P of sows was increased ($P < 0.05$) with 15% FMF supplementation. Therefore, the present study indicates that supplementing sow diets with 15% FMF from parturition to weaning has the potential to 1) increase sow ADFI, milk production, milk IgA content, and nutrient digestibility and promote sow reproductive performance by shortening the weaning-to-estrous interval and 2) promote the growth performance of their progeny and decrease diarrhea incidence.

Key words: apparent total tract digestibility, fermented corn and soybean meal mixed feed, milk, performance, progeny, sow

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INTRODUCTION

Sufficient nutrient intake is critical for lactating sows to meet the greater milk yield and better litter performance in modern swine production (Kim et al., 2008; Shen et al., 2011). Therefore, proper nutritional management to increase sow productivity has gained wide attention.

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Fermented feed (**FF**) has been widely investigated as a potential alternative to the use of growth-promoting antibiotics in swine production (Plumed-Ferrer and von Wright, 2009). Microbial fermentation using bacteria or fungi is capable of degrading antinutritional compounds, undigested components, and some large-size nutrients in feed while providing probiotics and their metabolites (Urlings et al., 1993; Olstorpe et al., 2010; Kiarie et al., 2011). Feeding FF has been well established to increase the bioavailability of feed, improve swine microbial ecology balance, enhance gut health, and decrease diarrhea rate and thereby benefit growth performance and host health (Canibe and Jensen, 2003; Kiers et al., 2003; Rahman et al., 2015; Missotten et al., 2015).

Previous study has reported the beneficial effects of FF on the reproductive and lactation performance of sows and the growth performance of piglets (Demečková et al., 2002). In our recent study, solid-state fermentation with *Bacillus subtilis* and *Enterococcus faecium* effectively reduced antinutritional factors (**ANF**; soy antigenic protein, NDF, and phytic acid) in corn–soybean meal mixed feed (**MF**), and high lactic acid concentration and low pH in fermented mixed feed (**FMF**) were observed (Shi et al., 2017). However, whether feeding FMF can improve the performance of lactating sows and their progeny needs further study.

Therefore, in the present study, two experiments were carried out to study the effects of supplementing sow diets with FMF during lactation on the performance of sows and their progeny.

MATERIALS AND METHODS

Preparation of Fermented Mixed Feed

Bacillus subtilis ZJU12 used in the present experiment was isolated from traditional fermented food (pickled vegetables). *Enterococcus faecium* was obtained from Baolai-leelai Bio-tech Co. Ltd (Tai'an, P.R. China). Pilot production of FMF was carried out at the Guanghua Best Ecological Agriculture & Animal Husbandry Development Co., LTD, Fujian, P.R. China. A basal substrate including 40% corn, 40% soybean meal (**SBM**), and 20% wheat bran was mixed and supplemented with sterile water to achieve a 40% moisture content. Three hundred kilograms of wet mixed substrate was inoculated with *B. subtilis* (3×10^8 cfu/g) and *E. faecium* (10^8 cfu/g) and then transferred to a plastic bag equipped with a 1-way valve (Rou Duoduo Biotechnology Co., Beijing, P.R. China), sealed, and fermented at room temperature for 96 h. The chemical analysis of the MF and FMF is presented in Table 1.

Animals, Diets, and Experimental Design

The experimental protocols were approved by the Institutional Animal Care and Use Committee at Zhejiang University.

Experiment 1. Sixty sows (Yorkshire × Landrace) were randomly allocated to three treatment groups as follows: 1) sows fed a control diet from day 3 before parturition to weaning (control group; $n = 20$), 2) sows fed a basal diet supplemented with 7.5% FMF (7.5% FMF group; $n = 20$), and 3) sows fed a basal diet supplemented with 15% FMF (15% FMF group; $n = 20$). For the 7.5% FMF diet, we substituted 7.5% FMF and 1.5% soy oil for 7.5% corn and 1.5% fermented SBM. For the 15% FMF diet, we substituted 15% FMF and 3% soy oil for 15% corn and 3% fermented SBM. The diets were formulated based on equal CP and DE content and met the NRC (2012) nutrient requirements. The ingredients and compositions of the diets are provided in Table 2.

Experiment 2. Sixty sows (Yorkshire × Landrace) were randomly allocated to two treatment groups as follows: 1) sows fed a control diet from day 3 before parturition to weaning (control group; $n = 30$) and 2) sows fed a basal diet with 15% FMF from 3 d before parturition to weaning (15% FMF group; $n = 30$). For the 15% FMF diet, we substituted 15% FMF and 2% soy oil for 13% corn, 3% SBM, and

Table 1. Nutrient composition of fermented mixed feed (as-fed basis)

Item	MF	FMF
DM, %	91.21	90.07
CP, %	25.79	28.16
TCA-SP, %	4.58	18.14
EE, %	3.67	3.37
Ash, %	3.99	4.56
Ca, %	0.18	0.20
Total P, %	0.47	0.53
β-Conglycinin, mg/g	31.93	7.02
Glycinin, mg/g	63.68	8.46
pH	6.55	4.02
Lactic acid, mmol/kg	—	174.57
Live BS cells, cfu/g	—	6.4×10^8
Live EF cells, cfu/g	—	4.6×10^8

MF, corn–soybean meal mixed feed. Analyzed values determined in duplicate; FMF, fermented mixed feed (40% corn, 40% soybean meal, and 20% wheat bran); TCA-SP, trichloroacetic acid–soluble protein (small peptides); EE, ether extract; BS, *Bacillus subtilis*; EF, *Enterococcus faecium*.

Table 2. Ingredient composition and nutrient concentration in experiments 1 and 2[1] (as-fed basis)

	Experiment 1 diet[2]			Experiment 2 diet[2]	
Item	Control	7.5% FMF	15% FMF	Control	15% FMF
Ingredient, %					
Corn	60	52.5	45	65	52
Soybean meal, dehulled	8	8	8	9	6
Extruded soybean	11	11	11	14.0	14.0
Fermented soybean meal	5.0	3.5	2.0	—	—
Alfalfa meal	3.0	3.0	3.0	2.0	2.0
Fish meal	3.0	3.0	3.0	3.0	3.0
Soy oil	—	1.5	3.0	—	2.0
FMF	—	7.5	15	—	15
Yeast hydrolysate	3.8	3.8	3.8	1.0	1.0
Citric acid	—	—	—	1.0	—
Baking soda	0.2	0.2	0.2	0.1	0.1
Salt	0.40	0.40	0.4	0.40	0.40
Limestone	0.6	0.6	0.6	0.5	0.5
Premix[3]	5.0	5.0	5.0	4.0	4.0
Total	100.00	100.00	100.00	100.00	100.00
Analyzed composition					
GE, MJ/kg	16.02	15.77	15.80	15.63	15.43
DM, %	88.28	87.54	87.12	88.78	87.35
CP, %	17.49	17.83	17.76	18.79	17.48
EE, %	4.80	5.01	5.32	4.80	4.98
Ash, %	6.59	6.99	6.68	5.77	5.93
Ca, %	0.95	1.04	0.93	0.96	0.92
Total P, %	0.50	0.49	0.49	0.29	0.30

EE, ether extract.

[1] Analyzed values determined in duplicate.

[2] FMF = fermented mixed feed.

[3] Provided quantities of the following vitamins per kilogram of the complete diet: 10,000 IU vitamin A as vitamin A acetate, 1,500 IU vitamin D_3 as D-activated animal sterol, 50 IU vitamin E as alpha tocopherol acetate, 4.4-mg vitamin K_3 as menadione dimethylpyrimidinol bisulfite, 3.0-mg thiamin as thiamine mononitrate, 6.0-mg riboflavin, 3.0-mg pyridoxine as pyridoxine hydrochloride, 0.04-mg vitamin B_{12}, 23-mg D-pantothenic acid as calcium pantothenate, 36-mg niacin, 0.8-mg folic acid, 0.15-mg biotin, and 186-mg choline as choline chloride. Also provided the following quantities of minerals per kilogram of the complete diet: 50-mg Cu as copper sulfate, 80-mg Fe as ferrous sulfate, 0.30-mg I as potassium iodate, 20-mg Mn as manganese sulfate, 0.2-mg Se as sodium selenite, and 95-mg Zn as zinc sulfate.

1% citric acid. The diets were formulated based on equal CP and DE content and met the NRC (2012) nutrient requirements. The ingredients and compositions of the diets are provided in Table 2.

Animal Management. All diets used were mixed with 40% water and fed directly to sows. On day 111 of gestation, the sows were moved to farrowing crates (2.50 by 1.80 m) and fed approximately 2.0 kg of diet each day until parturition. On the first 3 d postpartum, the sows were gradually given more feed (from 0 to 4 kg). From day 4 postpartum to weaning, the sows were fed ad libitum. The piglets were weaned at the age of 22 d. Within 24-h postpartum, the numbers of total born and live born and the litter birth weight were recorded. Within 24 h after weaning, the number of piglets that survived and the weaning litter weight were recorded. The feed intake of the sows from parturition to weaning was recorded. The backfat of sows was measured on the days of parturition and weaning. It was measured 6 cm above the midline, directly above the last rib on the left and right sides of the animal, using a Renco Meter (MS Schippers). The weaning-to-estrus intervals (**WEIs**) were tracked after weaning. The incidence of diarrhea in piglets was record during lactation.

Sample Preparation and Chemical Analyses

All diet, MF, FMF, and fecal samples were ground through a coffee grinder and then sieved through a 1-mm screen before chemical analysis. All samples were analyzed for GE according to Lin et al. (1987), DM (method 930.15; AOAC International, 2005), CP (method 984.13; AOAC International, 2005), ether extract (method 920.39A), and ash (method 942.05). Calcium and total P contents were determined by inductively coupled plasma emission spectroscopy (method 985.01; AOAC International, 2005). Trichloroacetic acid–soluble protein (**TCA-SP**) of MF and FMF were determined as described by Ovissipour et al. (2009). The contents of glycinin and β-conglycinin in ingredients were analyzed using an indirect ELISA kit (Longzhoufangke Bio Co., Beijing, P.R. China) according to the manufacturer's protocol.

Determination of Milk Yield and Quality. Milk yield was determined using the weigh–suckle–weigh method (Klaver et al., 1981). On day 21 after parturition, the weights of the litters were measured before and after suckling for nine continuous hours. The milk yield was calculated based on the following formula: milk yield in 24 h = 24 × Σ(litter weight after suckling − litter weight before suckling)/9.

On day 12 postpartum, 30 mL of milk was collected from sows in experiment 2 and stored at −20°C until analysis. Sixteen sows of each group in experiment 2 were randomly chosen. The protein, fat, sugar, and DM contents of the milk were determined using an FOSS MilkoScan FT120 (Foss Analytical A/S, Hillerød, Denmark). The contents of IgA in the milk were analyzed using a Porcine Immunoglobulin A (**IgA**) kit (Jiangsu Meibiao Biological Technology Co., Ltd., Jiangsu, P.R. China) according to the manufacturer's protocol.

Apparent Total Tract Digestibility

In experiment 2, the sows were fed diets with 0.3% chromic oxide to determine the apparent total tract digestibility (**ATTD**) of energy and nutrients from day 16 to 22. The uncontaminated feces were continuously collected from each sow for 10 h from 0800 to 2000 h on d 20 through 22. After collection, the fecal samples were thawed and mixed within pen and diet and then dried at 55 °C for 48 h. The dry fecal samples were ground through a 1-mm screen in a coffee grinder before chemical analysis.

Calculation and Statistical Analysis

The energy and nutrient digestibility for DM, GE, CP, Ca, and total P were determined using the following equation: ATTD (%) = 100 − [(marker D/marker F) × (nutrient F/nutrient D) × 100], in which marker D is the percent chromic oxide in the assay diet, marker F is the percent chromic oxide in the fecal samples, nutrient F is the percent nutrient in the fecal samples, and nutrient D is the percent nutrient in the assay diet.

Data for the two experiments were analyzed using SPSS software (SAS Inc., Chicago, IL). One-way ANOVA analysis followed by Tukey's multiple comparison tests was used to determine the statistical significance of multiple comparisons in experiment 1, and independent sample *t*-tests were used for comparisons of the two groups in experiment 2. The sow was the experimental unit for the two experiments, and the differences between the two treatments' means were considered significant at $P < 0.05$ and considered trends at $P < 0.10$.

RESULTS

Chemical Composition

Analyzed nutrient contents of the MF and FMF are presented in Table 1. Compared with the unfermented MF, the FMF contained greater concentrations of CP, ash, Ca, and total P. However, the crude fat was lower in the FMF than in the unfermented MF. The content of TCA-SP (<10 kDa) in the untreated MF was 4.58%, whereas in FMF, that content increased to more than four times as much. A co-fermentation using *B. subtilis* and *E. faecium* resulted in the degradation of 78.0% of β-conglycinin and 86.7% of glycinin in the MF. Also, the FMF had a greater amount of live *B. subtilis* and *E. faecium*, which were approximate 6.4×10^8 and 4.6×10^8, respectively. Additionally, higher lactic acid content and lower pH of the FMF, 174.57 mmol/kg and 4.02, respectively, were detected compared with the MF.

Experiment 1

As illustrated in Table 3, the litter total born size, live born size, and size at weaning were similar among the treatments. Compared with the control diet, supplementation with 7.5% FMF did not show any tendency to improve the performances of sows and their progeny. However, supplementation with 15% FMF significantly increased ($P < 0.05$) the sow ADFI compared with the control diet. Although the 15% FMF supplementation did not affect the litter weaning weight and the litter weight gain during lactation, it significantly increased ($P < 0.05$) the individual piglet weight at weaning and piglet weight gain compared with the control diet. In addition, the backfat loss of sows fed the 15% FMF diet was significantly lower ($P < 0.05$) than that of sows fed the control diet.

Table 3. Effects of supplementation with FMF (7.5 and 15%) during lactation on the performance of the sows and their progeny

Item	Diet			SEM	P-value
	Control	7.5% FMF	15% FMF		
Sow					
ADFI,[1] kg/d	5.50^{b}	5.93^{ab}	6.62^{a}	0.18	0.026
Backfat lost,[2] mm	3.00^{a}	1.25^{b}	1.42^{b}	0.30	0.061
Litter					
Size at birth, total	15.63	14.63	15.00	0.50	0.719
Size at birth, live	14.75	14.38	14.00	0.53	0.895
Size at weaning	11.91	12.13	11.14	0.20	0.156
Weaning alive rate,[3] %	93.60	94.50	96.33	1.01	0.094
Wt at birth, kg	18.72	17.99	18.65	0.67	0.894
Wt at weaning, kg	70.35	71.99	73.21	1.67	0.793
Wt gain,[4] kg	53.63	54.01	58.63	1.82	0.465
Diarrhea incidence,[5] %	2.11	1.95	1.83	0.21	0.870
Piglet					
Wt at birth,[6] kg	1.27	1.26	1.34	0.03	0.555
Wt at weaning,[7] kg	5.93^{b}	5.94^{b}	6.45^{a}	0.10	0.036
Wt gain,[8] kg	4.52^{b}	4.44^{b}	5.13^{a}	0.12	0.034

Letters a and b indicate means within a row with different superscripts significantly differ ($P < 0.05$).

[1] ADFI of the sows were recorded from parturition until weaning (22 d).

[2] Backfat loss = parturition backfat − weaning backfat.

[3] Litter weight gain = litter weight at weaning − litter weight at birth.

[4] Weaning alive rate = [litter size at weaning (live) − litter size at birth (live)]/litter size at birth (live).

[5] Diarrhea incidence = total diarrhea piglets/[litter size at birth (live) × trial days].

[6] Piglet weight at birth = litter weight at birth/litter size at birth (live).

[7] Piglet weight at weaning = litter weight at weaning/litter size at weaning (live).

[8] Piglet weight gain = piglet weight at weaning − piglet weight at birth.

Experiment 2

Table 4 indicates that 15% FMF supplementation significantly increased ($P = 0.004$) the sow ADFI and decreased ($P = 0.015$) backfat loss during lactation and tended to reduce the WEI ($P = 0.054$). Compared with control group, feeding 15% FMF to sows increased ($P < 0.05$) the weaning weight and weight gain of litters and elicited an increase ($P < 0.05$) in the weight gain of individual piglets. Additionally, the diarrhea incidence of piglets in FMF group was markedly reduced ($P < 0.05$) compared with that in control group.

The 15% FMF treatment significantly increased ($P < 0.05$) the milk yield and the IgA content of the milk. The protein, fat, and lactose contents of the milk did not differ between the two treatments.

As shown in Table 5, 15% FMF inclusion improved ($P < 0.05$) the ATTD of GE, DM, and total P of sows during lactation and elicited a tendency to increase ($P = 0.051$) the ATTD of CP compared with the control diet.

DISCUSSION

Previous studies have demonstrated the growth benefits and health-promoting effects of FF (Missotten et al., 2015; Mukherjee et al., 2016). The beneficial properties of FF have been attributed to increased feed intake (Canibe and Jensen, 2003), increased nutrient utilization (Feng et al., 2007), improved gut health (Canibe et al., 2008), and modulation of the immune system (Wang et al., 2011). In the present study, we used corn and SBM as the fermented substrates, which is the most commonly used feed for animal production in China, and obtained fermented corn and SBM mixed feed using *B. subtilis* and *E. faecium* co-fermentation. *Bacillus subtilis* is effective at degrading ANFs and macromolecular nutrients as the consequence of large amounts of extracellular enzyme secretion (Chi and Cho, 2016). Meanwhile, *Lactobacillus* spp. can efficiently proliferate and mainly produces lactic acid, which reduces the pH of the substrates (Missotten et al., 2015). Therefore, we combined these two probiotics to obtain a novel type of FMF.

Table 4. Effects of supplementation with 15% FMF on the performance of the sows and litters

Item	Diet		SEM	*P*-value
	Control	15% FMF		
Sow				
ADFI,[1] kg/d	4.66^b	5.50^a	0.15	0.004
Backfat lost,[2] mm	2.41^a	1.36^b	0.22	0.015
Weaning-to-estrus interval, d	7.54	5.36	0.57	0.054
Litter				
Size at birth, total	10.36	11.55	0.57	0.326
Size at birth, live	9.45	10.64	0.64	0.341
Size at weaning	9.27	9.54	0.21	0.539
Weaning alive rate,[3] %	94.70	97.01	1.21	0.354
Wt at birth, kg	14.41	13.69	0.45	0.440
Wt at weaning, kg	52.15^b	60.11^a	2.03	0.047
Wt gain,[4] kg	35.45^b	44.06^a	1.98	0.026
Diarrhea incidence,[5] %	5.25^a	2.98^b	0.57	0.045
Piglet				
Wt at birth,[6] kg	1.45	1.40	0.05	0.650
Wt at weaning,[7] kg	5.63	6.33	0.19	0.067
Wt gain,[8] kg	3.92^b	4.73^a	0.18	0.025
Milk				
Yield, kg	8.57^b	9.81^a	0.31	0.045
Fat, %	7.48	7.76	0.39	0.747
Lactose, %	5.71	5.87	0.11	0.498
Protein, %	4.79	4.80	0.096	0.987
IgA,[9] mg/mL	4.35^b	5.72^a	0.35	0.047

Letters a and b indicate means within a row with different superscripts significantly differ ($P < 0.05$).

[1] ADFI of the sows were recorded from parturition until weaning (22 d).

[2] Backfat loss = parturition backfat − weaning backfat.

[3] Weaning alive rate = [litter size at weaning (live) − litter size at birth (live)]/litter size at birth (live).

[4] Litter weight gain = litter weight at weaning − litter weight at birth.

[5] Diarrhea incidence = total diarrhea piglets/[litter size at birth (live) × trial days].

[6] Piglet weight at birth = litter weight at birth/litter size at birth (live).

[7] Piglet weight at weaning = litter weight at weaning/litter size at weaning (live).

[8] Piglet weight gain = piglet weight at weaning − piglet weight at birth.

[9] Immunoglobulin A content in the milk.

Table 5. Apparent total tract digestibility of energy and nutrients of the sows in experiment 2

Item	Diets		SEM	*P*-value
	Control	15% FMF		
GE	82.65^b	83.92^a	0.23	0.001
DM	83.13^b	84.18^a	0.26	0.037
CP	84.53^b	86.29^a	0.46	0.051
EE	58.73	63.92	1.72	0.145
Ash	37.20	40.82	2.22	0.448
Ca	40.93	48.06	0.20	0.123
Total P	36.10^b	41.99^a	1.44	0.041

Letters a and b indicate means within a row with different superscripts signifcantly differ ($P < 0.05$).

EE, ether extract.

In the present study, the FMF had greater concentrations of CP than the unfermented feed. Additionally, the FMF also exhibited an increase in TCA-SP compared with raw MF. Trichloroacetic acid–soluble protein is assumed to consist of small molecular peptides (2 to 20 AA residues) and free AA and di- and tripeptides, which can be directly absorbed in the animal gut system (Gilbert et al., 2008). Seo and Cho (2016) reported that *B. subtilis* fermentation can improve the nutritional quality of SBM mainly by degrading trypsin inhibitors and β-conglycinin. The ELISA analysis also showed that after co-fermentation, the contents of β-conglycinin and glycinin in MF were degraded by 78.0% and 86.7%, respectively. Therefore, an increase of TCA-SP may be mainly due to the degradation of macromolecular proteins (especially antigenic proteins). Furthermore, FMF had greater amount of lactic acid and live probiotics. The FMF diets were fed with 50% water to maintain the activity of live probiotics. Therefore, the FMF not only contained a lower amount of ANF, greater CP, and small peptides contents compared with the untreated MF but also provided abundant live *B. subtilis* and *E. faecium* cells and their metabolites such as lactic acid and enzymes to sows.

From the results of experiment 1, we found that supplementing sow diets with 15% FMF was more efficient than supplementation with 7.5% FMF in terms of improving the performance of the sows and their progeny, as illustrated by the improvements in the ADFI of the sows, increases in the individual piglet weaning weights, and piglet weight gains and reduced sow backfat loss. Therefore, we performed experiment 2 to verify the beneficial effects of supplementing sow diets with 15% FMF.

The results of experiment 2 indicated that 15% FMF supplementation increased the ADFI of sows, litter weaning weight, litter weight gain, and weight gain of individual piglets. Wang et al. (2016) demonstrated that supplementing sow diets with 5% fermented SBM did not improve the litter weaning weight, the weaning weights, and the BW gain of individual piglets. Demečková et al. (2002) reported that feeding sows *Lactobacillus* spp.–fermented liquid feed can improve sow ADFI but had no influence on piglet growth performance. Multiple potential factors can explain these discrepancies. One possible explanation relies on the difference in FF composition. The FF used in the present study was MF including corn, SBM, and wheat bran, whereas the products used in the studies by Wang et al. (2016) and Demečková et al. (2002) were produced using only SBM or a complete swine diet. Another possible explanation may be the difference in supplementation volume, with proper supplementation volumes having the potential to strengthen the effects of FF. Also, different probiotics used to produce FF could affect the results. The combination of *B. subtilis* and *E. faecium* was used in the present study to take advantage of their combined probiotic properties.

Consistent with the improved piglet performance, 15% FMF improved the milk yield of lactating sows. However, the milk fat, lactose, and protein contents were similar between the two treatments. Shen et al. (2011) also demonstrated a tendency for improved milk production when a fermented product was added to sow's diets, whereas no changes were found in milk composition. Additionally, a fermented protein source positively affects lactating sows' nutrient digestibility (Wang et al., 2016). The present study also showed that the FMF treatment improved the ATTD of GE, DM, CP, and total P of sows, which suggests that the FMF also improved the nutrient utilization of the sows. Reports have shown that a sow's nutritional status affects its milk production and that the quantity and quality of milk are important to piglets' performance (Lewis et al., 1978; Kim et al., 2000). Therefore, the improved performance of the litter may be a consequence of the FMF-induced improvements in greater ADFI and nutrient digestibility, which resulted in the greater milk yield. Alexopoulos et al. (2004) demonstrated that *Bacillus* spp. induced significant increases in the ADFI and milk fat and protein content of sows. Jinsuk et al. (2015) also reported that the performance of sows and their piglets were increased with the supplementation of a combination of *B. subtilis* and *Lactobacillus acidophilus*. Therefore, live *B. subtilis* and *Lactobacillus* spp. may also be another factor that improved the performance of the sows and their progeny during lactation. Moreover, in addition to live *B. subtilis* and *E. faecium* used in the present study, their metabolites such as organic acids (Gao et al., 2012), functional oligosaccharides (Sriphannam et al., 2012), antimicrobial peptides (Majumdar and Bose, 1958), and digestive enzymes (Kim et al., 2007) may play important roles in the beneficial effects observed here.

Demečková et al. (2002) reported that colostrum from sows fed fermented liquid feed had higher immune activities. In experiment 2, 15% FMF was associated with a significant increase in IgA concentration in milk. Maternal milk contains mostly IgA derived from the intestine, which can prevent various pathogens in piglets (Bourne and Curtis, 1973). Therefore, a high IgA content in the milk may be an important factor that contributes to piglet performance. Consistent with this result, 15% FMF reduced the incidence of piglet diarrhea compared with the control group. Therefore, we speculated that 15% FMF could improve piglet growth performance by promoting their immunological status.

The health and physiological status of lactating sows affects not only their litter but also their reproductive performance in the following parity (Jang et al., 2013). In this study, the WEI was shortened by supplementation of 15% FMF during lactation compared with the control group, which may be due to the greater GE digestibility and the reduced sow backfat loss in the 15% FMF group (James E Pettigrew at University of Illinois, Urbana-Champaign, 1981; De Rensis et al., 2005).

In conclusion, supplementing sow diets with 15% FMF during lactation increased nutrient availability and nutrient utilization and also improved milk yield and milk IgA content. Meanwhile, piglet performance was improved and incidence of diarrhea was decreased. Additionally, 15% FMF promoted sow reproductive performance, as indicated by reduced backfat loss and shortened WEI. Therefore, 15% FMF may be included in lactating sow diets as a dietary strategy to improve the performance of sows and their progeny.

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