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Effects of supplementing growing-finishing pig diets with *Bacillus* spp. probiotic on growth performance and meat-carcass grade quality traits

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ABSTRACT - Seventy five pigs [(Landrace × Yorkshire) × Duroc] with an initial body weight of 23.3±1.40 kg were used in the present study to investigate the influence of supplementation of a *Bacillus* spp. combination as probiotic (0%, 0.01%, and 0.02% with basal diet) in growing-finishing pig diets on performance parameters with a feeding trial period of 16 weeks. Growth performance was analyzed at the start and at weeks 6, 12, and 16 of the experimental period. The entire experiment using probiotic supplementation in the diet revealed significant differences in average daily gain and gain:feed, but no effects on average daily feed intake. The result showed significant effects on digestibility of dry matter (0.002), nitrogen (0.069), and energy (0.099) at week 16; and number of fecal *Lactobacillus* (0.082, 0.041), *E. coli* (0.097, 0.052), and blood glucose (0.001, 0.049) at weeks 6 and 16. Dietary supplementation with *Bacillus* spp. probiotic resulted in a significant linear effect on sensory evaluation of meat color, drip loss at day 3, and carcass weight in pigs. In contrast, there was no significant difference in blood metabolic profiles and noxious gas emissions in this experiment. Dietary combination of *Bacillus* spp. can be used as a probiotic for enhancing the growth performances and carcass quality of growing-finishing pigs.

Key Words: nutrient digestibility, fecal microflora, growing-finishing pigs

Introduction

Probiotics have received considerable attention as suitable alternatives of antibiotics to promote growth in the pig industry (Chen et al., 2006; Meng et al., 2010; Yan and Kim, 2011). Using antibiotics as growth promoters in animal feeds has been forbidden since 2011 (Global Agricultural Information Network, 2011) in South Korea. Among several bacterial species used as probiotics, spore-forming *Bacillus* spp. has been considered the most appropriate probiotic as its spores can resist harsh environments, thus allowing extensive storage at ambient temperature (Fuller, 1989; Hong et al., 2005).

Previous studies on dietary supplementation with *Bacillus* spp. product in pigs have reported favorable results (Hong et al., 2002; Gracia et al., 2004; Wang et al., 2009; Yan and Kim, 2011). In growing-finishing pigs, dietary probiotics could improve weight gain, feed conversion ratio (FCR), and feed intake (FI) (Alexopoulos et al., 2004; Timmerman et al., 2004; Česlovas et al., 2005; Chen et al., 2005; Shon et al., 2005; Davis et al., 2008; Ganeshkumar et al., 2009). It has been well accepted that dietary probiotics could benefit animal performance by producing antibacterial substances in their intestines (Hentges, 1992) by competing with harmful gut flora and stimulating the immune system (Khajarern and Khajarem, 1994).

However, reports on feeding a combination of *Bacillus* spp. probiotic to growing-finishing pigs are rare. We hypothesized that supplementation of *Bacillus* spp. probiotic could influence the growth performance, nutrient digestibility, fecal microflora, and carcass grade in pigs. Therefore, the focal aim of this study was to investigate the effect of *Bacillus* spp.-based probiotic on growth performance traits, apparent total tract digestibility, blood parameters, fecal microflora, excreta noxious gas emission, and meat quality and carcass grades of growing-finishing pigs and determine the optimal level of this probiotic for pigs.

Material and Methods

The experimental protocols describing the management and care of animals were reviewed and approved by the Animal Care and Use Committee of Dankook University (DK-3-1504).

In this study, commercially available *Bacillus*-based probiotic (SynerZymeH10, SynerBig®, South Korea), containing *B. coagulance* (1×10^9 cfu/g), *B. lichenformis* (5×10^8 cfu/g), and *B. subtilis* (1×10^9 cfu/g), was used for

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the experiment. A total of 75 pigs [(Landrace × Yorkshire) × Duroc] with a starting weight of 23.3±1.40 kg were used for a 16-week feeding trial. The following three feed rations consisting of soybean meal supplemented with or without *Bacillus* based probiotic were fed to pigs: CON (basal diet); CON + 0.01% *Bacillus* spp. probiotic; and CON + 0.02% *Bacillus* spp. probiotic. These dietary treatments were given as phase I (Grower, 0-6 weeks) and phase II (Finisher, 6-16 weeks) (Table 1) to analyze the growth performance traits in experiment pigs.

Grower pigs were allocated randomly to three treatment groups consisting of five replicate pens per treatment with five pigs (three barrows and two gilts) per pen. Pens measured 1.8 m × 1.8 m each with slatted plastic flooring. All pens had one self-feeder and a nipple drinker to provide pigs with access to feed and water *ad libitum*. Ventilation was delivered by a mechanical system with automatic adjustments to provide 12 h of artificial light per day. The room temperature of approximately 30 °C was maintained and 1 °C was reduced for each succeeding week. Diets were provided in mash form and were formulated to comply with National Research Council (NRC, 2012) recommendations of nutrient requirements for swine.

Table 1 - Ingredients and chemical composition of complete diets (g/kg, as fed basis)

	Grower	Finisher
Ingredient		
Corn	474	566.3
Wheat	30	20
Molasses	40	40
Wheat bran	30	-
Corn gluten feed	19	20
Soybean meal	306	249
Rapeseed meal	20	20
Corn germ meal	-	10
Lysine (80%)	1	0.6
Methionine (99%)	0.4	-
Tallow (liquid)	50	46
Limestone	9.3	12.3
Di-calcium phosphate	15.6	11.3
Salt	2	2
Vitamin premix[1]	1.5	1.5
Mineral premix[2]	1	1
Calculated composition		
Crude protein	194.1	171.2
Crude fat	76.3	74.1
Crude fiber	31.0	27.6
Crude ash	58.1	53.2
Calcium	8.0	8.0
Total phosphorus	6.0	5.0
Available phosphorus	3.5	2.7
Total lysine	11.3	9.5
Methionine	3.5	2.8
Available methionine	3.1	2.5
Analyzed composition		
Metabolize energy, MJ/kg	13.21	13.80
Crude protein	195.6	170.5
Crude fat	76	73.2
Crude fiber	32.3	27.9
Crude ash	58.5	53.1
Calcium	8.1	8.0
Total phosphorus	5.9	5.1
Total lysine	11.8	9.8
Methionine	3.7	2.9

[1] Provided per kilogram of complete diet: 1.3 mg vitamin A (Retinol); 0.022 mg vitamin D_3 (Cholecalciferol); 45 mg vitamin E (Tocotrienol); 4.2 mg vitamin K_3 (Menodione); 24.6 mg vitamin B_5 (d-Ca-pantothenate); 8.6 mg vitamin B_2 (Riboflavin); 0.04 mg vitamin B_{12} (Cobalamins).
[2] Provided per kilogram of complete diet: 15 mg Cu; 80 mg Fe; 56 mg Zn; 73 mg Mn; 0.3 mg I; 0.5 mg Co; 0.4 mg Se.

Pigs were weighed at day 0 and on weeks 6, 12, and 16 of the experimental period, while feed intake was recorded on a per-pen basis to calculate average daily gain (ADG), average daily feed intake (ADFI), and gain:feed (G:F) ratio.

Chromium oxide (Cr_2O_3, 2 g/kg) was added to diets as an indigestible marker to measure digestibility. Fresh fecal samples were collected directly via rectal massage from at least two pigs in each pen at weeks 6 and 16 of the experiment to determine the apparent digestibility of dry matter (DM), energy (E), and nitrogen (N), according to AOAC (2007). All fecal and feed samples were stored at −20 °C until analyzed. They were dried at 60 °C for 72 h and ground to pass through a 1-mm screen. Chromium was analyzed by UV absorption spectrophotometry (Shimadzu UV-1201, Shimadzu, and Kyoto, Japan) using the method of Williams et al. (1962).

Digestibility was calculated using the following formula:

$$ATTDC = [1 - \{(N_f \times C_d)/(N_d \times C_f)\}] \times 100,$$

in which ATTDC = apparent total tract digestibility coefficient; N_f = nutrient concentration in feces (% DM); N_d = nutrient concentration in diets (% DM); C_f = chromium concentration in feces (% DM); and C_d = chromium concentration in diets (% DM).

One gram of composite fecal sample from each pen was diluted with sterile saline (10^{-7} to 10^{-3}) and homogenized. Viable counts of bacteria in fecal samples were determined by plating serial 10-fold dilutions (in 1% peptone solution) onto MacConkey agar plates or MRS agar plates (Difco, USA) to isolate *E. coli* or *Lactobacillus*, respectively. The number of colonies of *E. coli* and *Lactobacillus* was counted immediately after incubation at 37 °C for 38 h.

The NH_3 concentration was then determined using the method described by Chaney and Marbach (1962). To determine the fecal H_2S and total mercaptans (R.SH) concentration, 300 g of fresh fecal samples were transferred to a sealed box and fermented in an incubator for 30 h (35 °C). The fermented samples were then analyzed with a gas search probe (Gastec Model GV-100, detector tube

No. 4LL, 4LK for H_2S; No.70 and 70L for R.SH, Gastec Corp., Kanagawa, Japan).

For the blood characteristics, two pigs from each pen were randomly selected and blood samples were collected via anterior vena cava puncture at weeks 6 and 16, collected into both non-heparinized tubes and vacuum tubes containing K_3EDTA (Becton, Dickinson and Co., Franklin Lakes, NJ, USA) to obtain the serum and whole blood, respectively. Serum samples were centrifuged (3000 × g) for 15 min at 4 °C. White blood cell (WBC), red blood cell (RBC), lymphocyte, and glucose concentrations in the whole blood were determined with an automatic blood analyzer (ADVIA 120, Bayer, NY).

Backfat thickness (BFT) was measured at weeks 6, 12, and 16. Lean meat percentage was measured at weeks 12 and 16 using Pig-log 105 (Carometec food technology, Denmark) at P2 position (6.5 cm area on the right and left end frames). Lean meat percentage was provided by a packing plant after calculating with a proprietary equation according to NPPC (1999) procedures.

At the end of the experiment, pigs were slaughtered when they reached an average body weight (BW) of 110 kg at a local commercial slaughterhouse. Carcasses were chilled at 2 °C for 24 h. A sample of the right loin was removed between the 10th and 11th ribs. Meat samples were thawed at 26 °C before evaluation. Subjective meat color, marbling, and firmness scores were evaluated according to NPPC (1991) standards. Immediately after subjective tests, values of L* (lightness = 89.2), a* (redness = 0.921), and b* (yellowness = 0.783) were measured at three surface locations of each sample using a chromameter Model CR-410 (Konica Minolta Sensing Inc., Osaka, Japan). Duplicate pH values of each sample were directly measured using a pH meter (Istek, Model77p).

Water-holding capacity (WHC) was measured using the method of Kauffman et al. (1986). Briefly, a 0.3 g sample was pressed onto a 125-mm-diameter piece of filter paper at 3000 × g for 3 min. The areas of the pressed samples and expressed moisture were delineated and determined using a digitizing area-line sensor (MT-10S, M.T. Precision Co. Ltd., Tokyo, Japan). The water area:meat area ratio was then calculated as a measure of WHC, in which a smaller ratio indicated increased WHC. *Longissimus* muscle area (LMA) was measured by tracing the *longissimus* muscle surface at the 10th rib using the aforementioned digitizing area-line sensor. Drip loss was measured for approximately 2 g of meat sample using the plastic bag method described by Honikel (1998). Cook loss was determined using the published method of Sullivan et al. (2007). Backfat thickness (mm), carcass weight, and carcass grade were measured. The quality of pork carcasses was graded into "Grade 1+," "Quality Grade 1," or "Grade 2", based on characteristics such as marbling, lean color, and conditions of belly streaks (KAPE, 2010). Carcass BFT was adjusted to a live weight of 115 kg, as described previously (Ha et al., 2010).

Data were analyzed statistically by analysis of variance, using general linear model (GLM) procedure of SAS/STAT® (Statistical Analysis System, version 9.2) software for a completely randomized design. Mean values and standard errors of the mean (SEM) are reported. Orthogonal polynomial contrast wasx conducted to measure the linear and quadratic effects for increasing the *Bacillus* spp. probiotic levels on all measurements. A probability value of $P \leq 0.05$ was considered to be statistically significant and trends were noted under conditions of $0.05 < P < 0.10$.

Results

The results for growth performance indicated *Bacillus spp*. probiotic supplementation had a linear trend on ADG and G:F (P = 0.052 and P = 0.062, respectively) at week 16 and a significant linear effect on ADG and G:F (P = 0.041 and P = 0.019, respectively) in the overall experiment. However, no differences were observed among dietary treatments on ADFI during the entire period (Table 2). A significant linear effect on nutrient digestibility of DM (P = 0.002) and a linear trend on N (P = 0.069) as well as E (P = 0.099) at week 16 were observed in pigs fed 0.2% *Bacillus*-based probiotic diets (Table 3).

Probiotic supplementation had no significant (P>0.05) effect on live BFT or lean meat percentage of growing-finishing pigs (Table 4). When more *Bacillus* spp. probiotic was added to diets, increasing linear effects were observed on glucose (P = 0.001, P = 0.049) at weeks 6 and 16. However, the probiotic-supplemented diet for growing-finishing pigs had no significant (P>0.05) effect on RBC, WBC, or lymphocyte concentrations (Table 5).

The present data indicate that *Bacillus* spp. probiotic supplementations has effects on fecal microflora in growing-finishing pigs. There was a linear trend of probiotic supplementation on the number of *Lactobacillus* and *E. coli* at week 6 (P = 0.082 and P = 0.097, respectively) and a significant linear effect on the number of *Lactobacillus* and *E. coli* at week 16 (P = 0.041 and P = 0.052, respectively; Table 6). However, the probiotic supplementation had no significant (P>0.05) effect on excreta fecal noxious gas (NH_3, H_2S, R.SH) emissions during the entire experimental period (Table 6).

The dietary supplementation with a combination of *Bacillus* spp. as a probiotic had as significant linear effect

on the sensory attribute meat color (P = 0.025), drip loss at day 3 (P = 0.013), and carcass weight (P = 0.034) of growing-finishing pigs. Interestingly, carcass quality grade was highly correlated with marbling and meat color as well as BFT to some extent, when the grade was quantified. We observed that "1+" carcass grade was higher in pigs fed *Bacillus* spp.-based probiotic than CON (Table 7). However, the probiotic diets failed to have a significant effect (P>0.05) on marbling, firmness, cooking loss, pH, LMA, and WHC values and BFT in this experiment.

Table 2 - Effects of *Bacillus* spp. probiotic supplementation on growth performance in growing-finishing pigs

Variable	CON	T1	T2	SEM	P-value	
					Linear	Quadratic
Body weight, kg						
Initial	23.28	23.31	23.31	0.66	0.983	0.990
Week 6	52.87	53.84	53.62	1.15	0.650	0.669
Week 12	84.71	86.25	86.33	1.46	0.452	0.694
Week 16	107.23	109.53	109.98	1.42	0.202	0.607
Week 6						
ADG, g	705	727	722	14	0.389	0.439
ADFI, g	1568	1547	1540	29	0.508	0.858
G:F	0.449	0.470	0.469	0.012	0.289	0.476
Week 12						
ADG, g	758	772	779	11	0.212	0.815
ADFI, g	2341	2277	2303	28	0.352	0.219
G:F	0.324	0.339	0.338	0.008	0.218	0.409
Week 16						
ADG, g	804	832	844	13	0.052*	0.668
ADFI, g	2819	2771	2770	41	0.436	0.641
G:F	0.285	0.300	0.305	0.007	0.062**	0.579
Overall						
ADG, g	750	770	774	8	0.041*	0.402
ADFI, g	2171	2127	2134	16	0.137	0.233
G:F	0.345	0.362	0.363	0.005	0.019*	0.171

SEM - standard error of the mean.
CON - basal diet; T1 - CON + 0.01% *Bacillus* spp. probiotic; T2 - CON + 0.02% *Bacillus* spp. probiotic.
ADG - average daily gain; ADFI - average daily feed intake; G:F - gain:feed.
* Significantly different at P<0.05; ** Trends at 0.05<P<0.10.

Table 3 - Effects of *Bacillus* spp. probiotic supplementation on nutrient digestibility in growing-finishing pigs

Variable (g/kg)	CON	T1	T2	SEM	P-value	
					Linear	Quadratic
Week 6						
Dry mater	749.3	753.8	751.1	0.83	0.878	0.728
Nitrogen	731.0	746.9	744.3	1.00	0.358	0.459
Energy	742.8	751.0	750.3	0.89	0.555	0.688
Week 16						
Dry mater	704.4	725.8	733.1	0.55	0.002*	0.309
Nitrogen	697.6	712.1	722.0	0.90	0.069**	0.837
Energy	701.7	719.1	722.0	0.83	0.099**	0.482

SEM - standard error of the mean.
CON - basal diet; T1 - CON + 0.01% *Bacillus* spp. probiotic; T2 - CON + 0.02% *Bacillus* spp. probiotic.
* Significantly different at P<0.05; ** Trends at 0.05<P<0.10.

Table 4 - Effects of *Bacillus* spp. probiotic supplementation on backfat thickness and lean meat percentage in growing-finishing pigs

Variable	CON	T1	T2	SEM	P-value	
					Linear	Quadratic
Back-fat thickness, mm						
Initial	10.4	10.2	10.1	0.3	0.566	0.962
Week 6	13.0	13.7	13.3	0.3	0.560	0.148
Week 12	15.3	15.7	15.6	0.3	0.388	0.383
Week 16	18.8	19.2	19.6	0.4	0.108	0.964
Lean meat, %						
Week 12	61.0	61.3	61.6	0.4	0.452	0.764
Week 16	52.8	53.3	53.6	0.5	0.352	0.915

SEM - standard error of the mean.
CON - basal diet; T1 - CON + 0.01% *Bacillus* spp. probiotic; T2 - CON + 0.02% *Bacillus* spp. probiotic.

Table 5 - Effects of *Bacillus* spp. probiotic supplementation on blood profiles and glucose level in growing-finishing pigs

Variable	CON	T1	T2	SEM	P-value	
					Linear	Quadratic
Week 6						
RBC, 10^{12}/L	5.67	5.99	5.76	0.31	0.849	0.486
WBC, 10^{9}/L	15.55	15.72	15.65	1.04	0.947	0.927
Lymphocyte, %	36.63	42.4	37.325	3.49	0.891	0.237
Glucose, mmol/L	4.60	5.05	4.994	1.01	0.001*	0.003
Week 16						
RBC, 10^{12}/L	6.04	6.79	6.48	0.24	0.235	0.109
WBC, 10^{9}/L	16.13	16.76	16.79	1.05	0.667	0.819
Lymphocyte, %	43.28	45.93	48.40	5.10	0.496	0.989
Glucose, mmol/L	4.88	5.05	5.32	3.04	0.049*	0.786

SEM - standard error of the mean; RBC - red blood cells; WBC - white blood cells.
CON - basal diet; T1 - CON + 0.01% *Bacillus* spp. probiotic; T2 - CON + 0.02% *Bacillus* spp. probiotic.
* Significantly different at P<0.05.

Table 6 - Effects of *Bacillus* spp. probiotic supplementation on fecal microbial and noxious gas emission in growing-finishing pigs

Variable	CON	T1	T2	SEM	P-value	
					Linear	Quadratic
Fecal microbial (log_{10}cfu/g)						
Week 6						
Lactobacillus	7.28	7.32	7.35	0.02	0.082**	0.886
E. coli	6.43	6.39	6.36	0.05	0.097**	0.920
Week 16						
Lactobacillus	7.34	7.36	7.41	0.03	0.041*	0.815
E. coli	6.48	6.45	6.43	0.04	0.052*	0.967
Excreta noxious gas emission (mg/kg)						
Week 6						
NH_3	3.9	3.1	3.4	0.3	0.334	0.227
H_2S	3.3	2.4	2.8	0.2	0.134	0.062
Total mercaptans	5.2	4.5	4.8	0.2	0.244	0.116
Week 16						
NH_3	12.8	12.3	12.6	0.6	0.813	0.634
H_2S	23.0	23.4	22.8	0.3	0.737	0.153
Total mercaptans	17.2	17.0	16.8	0.3	0.353	0.912

SEM - standard error of the mean.
CON - basal diet; T1 - CON + 0.01% *Bacillus* spp. probiotic; T2 - CON + 0.02% *Bacillus* spp. probiotic.
* Significantly different at P<0.05; ** Trends at 0.05<P<0.10.

Table 7 - Effects of *Bacillus* spp. probiotic supplementation on meat quality traits and carcass grades in growing-finishing pigs

Variable	CON	T1	T2	SEM	P-value	
					Linear	Quadratic
Meat color[1]						
L	58.27	58.51	58.74	1.02	0.754	0.998
a	17.08	17.23	17.49	0.51	0.582	0.932
b	6.14	6.26	6.06	0.51	0.914	0.809
Sensory evaluation						
Color	3.34	3.63	3.66	0.08	0.025*	0.245
Firmness	2.91	3.22	3.19	0.14	0.177	0.328
Marbling	1.88	2.03	2.03	0.14	0.442	0.654
Cooking loss, %	30.96	30.59	30.51	1.99	0.877	0.954
Drip loss, %						
Day 1	8.38	8.06	6.65	0.95	0.226	0.652
Day 3	13.97	13.52	12.38	0.37	0.013*	0.460
Day 5	19.01	17.7	17.5	0.98	0.306	0.653
Day 7	23.92	22.86	23.26	1.01	0.651	0.567
pH	5.31	5.34	5.36	0.07	0.621	0.931
Longissimus muscle area, cm^2	67.83	68.67	69.47	0.86	0.510	0.277
Water holding capacity, %	49.16	49.99	49.33	1.28	0.926	0.643
Carcass grade						
Carcass weight, kg	85.9	88.0	91.6	1.9	0.034*	0.799
Back-fat thickness, mm	17.7	18.5	16.8	1.0	0.488	0.302
1+, %	20	40	40	-	-	-
1, %	50	30	40	-	-	-
2, %	30	30	20	-	-	-

SEM - standard error of the mean.
CON - basal diet; T1 - CON + 0.01% *Bacillus* spp. probiotic; T2 - CON + 0.02% *Bacillus* spp. probiotic.
[1] L - lightness; a - redness; b - yellowness.
* Significantly different at P<0.05.

Discussion

The use of antibiotics for growth promotion has been banned since July 2011 in South Korea due to the anxiety over food safety. Probiotics are a group of non-pathogenic organisms that are known to have beneficial effects on the health of the host when administered in sufficient numbers (Reid et al., 2003). Hong et al. (2005) reported that various *Bacillus* spp. could be used as antibiotic alternatives for humans and animals. However, Sanders and Huisin't Veld (1999) suggested that the health effects of probiotics are genus-, species-, and strain-specific. According to some previous reports (Hong et al., 2002; Hong et al., 2005; Gracia et al., 2004; Wang et al., 2009; Meng et al., 2010; Yan and Kim, 2011), multi-strain probiotics are more beneficial than single-strain probiotics. Therefore, we chose three *Bacillus* spp. strains and combined them as probiotics.

Our results revealed that the *Bacillus spp.* probiotic had a significant linear (P<0.05) effect on ADG and G:F without affecting ADFI in growing-finishing pigs. Alexopoulos et al. (2004) also observed a significant (P<0.05) improvement in growth performance feeding finishing pigs a diet supplemented with *Bacillus*-based probiotic (*B. licheniformis* and *B. subtilis*). Jonsson and Conway (1992) suggested that dietary addition of *Bacillus* spp. could lead to increased growth performance and improved health of pigs. Shon et al. (2005) observed that growing-finishing pigs with direct-fed microbial diets have improved growth performance. Dietary supplementation with probiotics has been reported to significantly improve pork quality, produce more vivid color, reduce drip loss, and enhance water holding capacity of meat in finishing pigs (Jiang, 2011; Ma, 2011).

The growth performances of pigs fed the diets supplemented with the *Bacillus* based probiotic in the present study was related to privileged feed intake and enhanced feed efficiency. It increased ADG and decreased the fecal NH_3 concentration in pigs, which indicates that the *Bacillus* probiotics had a positive effect on pig performance. On the contrary, Munoz et al. (2007) reported that addition of 0.05% probitic complex (*B. licheniformis* and *B. subtilis*) to the diet of finishing pigs has no effect on ADG or G:F ratio, although it could improve ADFI. Kornegay and Risley (1996) similarly reported that diets supplemented with *Bacillus* have no effect on the growth performance of growing-finishing pigs, although it could improve ADFI (Davis et al., 2008).

Our results revealed that *Bacillus* probiotic had a significant (P<0.05) effect on the digestibility of DM. In addition, the probiotic-supplemented diet treatments caused a linear effect on N and E. The present study also reported improved digestibility of DM in pigs fed diets supplemented with probiotic, corroborating Choi et al. (2011). Therefore, we suggest that the reason for the improved growth performance and feed efficiency is likely to be the increased nutrient digestibility. In contrast, Chen et al. (2006) and Wang et al. (2009) found no effect of *Bacillus*-based multi-microbe probiotic products on the TTADC of DM or N in grower-finisher pigs. Kim et al. (1998) observed no effect of probiotic on the digestibility of finishing pigs. Kornegay and Risley (1996) found that supplementation of *Bacillus* product Biomate2B® (*B. subtilis* and *B. licheniformis*) and Pelletmate Livestock® (*B. subtilis*, *B. licheniformis*, and *B. pumilus*) in finishing pigs have no effect on the digestibility of nutrients (DM, NDF, ADF, ash, or N). Meng et al. (2010) observed that the *Bacillus*-supplemented diet showed increased digestibility in the growing phase, but not in the finishing phase of pigs. Our results on growth performance, meat quality, and nutrient digestibility were consistent with the results of Meng et al. (2010).

One of our objectives in the current study was to determine whether supplementation of *Bacillus* probiotic could improve the blood characteristics of pigs. However, our data indicated no influences on RBC, WBC, and lymphocyte when diets were incorporated with Bacillus probiotic, which is in agreement with our previous studies (Chen et al., 2005; 2006; Yan and Kim, 2011). According to Mohana Devi and Kim (2014), probiotic supplementation showed a significant (P<0.05) effect on glucose concentration in weanling pigs. Similarly, our result showed that the *Bacillus* probiotic had a significant (P<0.05) effect on glucose level during the entire experimental period. However, the mechanism is not fully yet understood; therefore, further research is still necessary to make a conclusion about the effect of probiotics on the blood characteristics.

In the present study, *Bacillus* spp.-based probiotic supplementation had a significant (P<0.05) effect on microflora concentrations in growing-finishing pigs. This indicates that the *Bacillus* spp. probiotic in our study has a beneficial effect on *Lactobacillus* counts and inhibits the increase in *E. coli*. Stavric and Kornegay (1995) reported that probiotics are more effective in animals during microflora development or when microflora stability has been impaired. However, *B. subtilis* H4 (6×10^{11} cfu/mL) supplementation has no effect on counts of fecal *Lactobacillus* and *E. coli* in neither growing nor finishing pigs (Giang et al., 2011). Probiotics could reduce environmental pollutants from animal manure by improving feed efficiency and nutrient retention (Han et al., 2001). However, dietary *Bacillus* spp.-based probiotic showed no significant effect on noxious gas emission in this study. Fecal noxious gas emission was related to nutrient digestibility because increased digestibility may allow less substrate for microbial fermentation in the large intestine, consequently decreasing fecal noxious gas emission (Yan and Kim, 2011).

Data indicated increased values of redness in the meat of growing-finishing pigs fed diets supplemented with *Bacillus* spp. probiotic in our study. Cho et al. (2005) also observed increased redness in the meat of pigs fed probiotic diets. Drip loss is commonly assessed as indicative of meat quality. Lower drip loss and higher WHC indicate better meat quality. The results of this experiment showed that drip loss was significantly lower in the probiotics treatment group than in the control group (P<0.05), indicating that probiotics reduced lipid peroxidation in the muscles by maintaining the integrity of cell membranes and reduced the rate of water loss, affecting WHC. Liu et al. (2013) also reported that dietary supplementation with probiotics significantly (P<0.05) reduced drip loss and cooking loss by 24.40% and 11.45%, respectively, compared with the control group.

In our present study, results for meat quality showed a significant effect on the sensory evaluation of color (P = 0.025). This may indicate that dietary supplementation of *Bacillus spp*. probiotic improved tenderness and palatability of pork. The supplementation of *Bacillus* spp. probiotic improved carcass weight (P<0.05) and carcass grade in this study. This was in agreement with findings of Kim (2005), Ceslovas et al. (2005), and Ganeshkumar et al. (2009), who also observed significantly higher carcass weight in pigs receiving *Bacillus* spp. probiotic supplementation. However, Chu et al. (2011) reported significantly decreased carcass weight in pigs fed diets supplemented with probiotic. Cui et al. (2013) reported that probiotic supplementation containing *B. subtilis* provided a 16.77% higher BFT as compared with CON. Alternately, our result showed no effects on BFT with probiotic supplementation. These contradictory results may be due to differences in bacteria species used and the pigs genotype (Rekiel et al., 2005).

Conclusions

Dietary supplementation with *Bacillus* spp. probiotic prepared at 0.2% is effective in improving the growth performance (average daily gain and gain:feed), nutrient digestibility of dry matter, fecal microbiota, glucose levels, sensory evaluation of meat color, drip loss, and carcass weight and grades in pigs without affecting average daily feed intake. Nevertheless, using *Bacillus* spp.-based complex probiotics to improve meat quality has been questioned because the results in pigs have been inconsistent.

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