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ARTICLE

Influence of *Enterococcus faecium* and endo-1,4-β-xylanase supplementation on growth performance, nutrient digestibility, fecal microflora, fecal gas emission, and meat quality in finishing pigs fed with diets based on corn–soybean meal

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Abstract: This study was conducted to evaluate the effect of *Enterococcus faecium* (EF) and endo-1,4-β-xylanase (XY) in finishing pigs. The pigs were randomly divided into four treatments with eight replications per treatment and four pigs per pen in a 2 × 2 factorial arrangement with two levels of EF (0 or 0.1 g kg^{-1} of feed) and XY (0 or 0.1 g kg^{-1} of feed). During 0–12 wk, average daily gain and gain to feed ratio (G:F) increased by addition of EF in the diets ($P < 0.05$). The G:F increased by addition of XY in the diets ($P < 0.05$). At the 6th week, the results showed that digestibility of dry matter (DM), nitrogen, and energy increased with pigs fed EF supplemented diet compared with diets without EF supplementation ($P < 0.05$). In addition, administration of XY improved DM digestibility compared with treatments without XY supplementation ($P < 0.05$). The fecal *Escherichia coli* and *Lactobacillus* counts decreased and increased respectively by addition of EF or XY in the diets ($P < 0.05$). In conclusion, providing finishing pigs with diets that contained EF and XY can improve growth performance, nutrient digestibility, *Lactobacillus* population, and decrease *E. coli* counts.

Key words: digestibility, growth performance, pigs, probiotics, xylanase.

Résumé : Cette étude a été effectuée pour évaluer les effets d'*Enterococcus faecium* (EF) et d'endo-1,4-β-xylanase (XY) chez les porcs en finition. Les porcs ont été aléatoirement divisés en quatre traitements avec huit répétitions par traitement et quatre porcs par enclos dans un plan expérimental factoriel 2 × 2, avec deux niveaux d'EF (0 ou 0,1 g kg^{-1} d'aliments) et de XY (0 ou 0,1 g kg^{-1} d'aliments). Pendant les semaines 0 à 12, le gain moyen quotidien et l'indice de consommation alimentaire (G:F – « gain to feed ratio ») ont augmenté par l'addition d'EF dans les diètes ($P < 0,05$). Le G:F a augmenté par l'addition de XY dans les diètes ($P < 0,05$). À la 6e semaine, les résultats montraient que la digestibilité des matières sèches (DM – « dry matter »), l'azote et l'énergie augmentaient chez les porcs ayant les suppléments d'EF par rapport à ceux n'ayant pas ces suppléments ($P < 0,05$). De plus, l'ajout de XY a amélioré la digestibilité des DM par rapport aux traitements sans suppléments de XY ($P < 0,05$). Les décomptes des bactéries fécales *Escherichia coli* et *Lactobacillus* ont diminué et augmenté respectivement avec l'ajout d'EF ou de XY dans les diètes ($P < 0,05$). En conclusion, offrir aux porcs en finition une diète qui contient l'EF et XY peut améliorer la performance de croissance, la digestibilité des éléments nutritifs, la population de *Lactobacillus* et diminuer les comptes d'*E. coli*. [Traduit par la Rédaction]

Mots-clés : digestibilité, performance de croissance, porcs, probiotiques, xylanase.

Introduction

Worldwide, there is a growing concern about the increased prevalence of antibiotic resistance. It is now generally accepted that the main risk factor for this increase in resistance in pathogenic bacteria is the increased use of antibiotics (van den Bogaard and

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Stobberingh 2000), which inevitably leads to the emergence and dissemination of resistant bacteria and resistance genes. Since then, many have tried to answer this challenge with the use of probiotics in animal nutrition. The addition of probiotics, which are health promoting live organisms, to pig diets, has been shown to improve the performance and nutrient digestibility, as well as the intestinal ecosystem (Choi et al. 2011). Černauskienė et al. (2011) reported that the supplementation of *Enterococcus faecium* (EF) contributed to an improvement in the performance parameters of finishing pigs. Yan and Kim (2013) demonstrated that dietary administration of EF improved total tract nutrient digestibility and intestinal microbial balance of growing–finishing pigs. Ileal and fecal *Lactobactilli* counts were increased and *Escherichia coli* numbers were decreased in pigs fed the diets supplemented with EF, and therefore may contribute towards excluding pathogen colonization in the host (Zhang and Kim 2015).

In addition, several studies have reported that enzyme supplementation also reduce the colonization of the gut by pathogens (Hübener et al. 2002). Xylanase may play a role in determining the gut microflora populations as a result of the dominant oligomers produced (Engberg et al. 2004). Previous researchers have noted that the xylo-oligosaccharides, released from the xylanase-mediated breakdown of arabino-xylan, can be hydrolyzed by beneficial bacteria such as *Bifidobacterium* and *Lactobacillus* spp. in the hindgut, resulting in increased synthesis of short-chain fatty acids (Wang et al. 2005; Thammarutwasik et al. 2009). The response of xylanase supplementation to diets based on corn–soybean meal improved growth performance, nutrient digestibility, fecal *Lactobacillus* counts, and decreased fecal NH_3 and H_2S emission in weaning pigs (Lan et al. 2017). Therefore, we hypothesized that there may be an interaction between probiotic and enzyme; this study was conducted to determine if single or combined supplementation of the diet of finishing pigs with EF and endo-1,4-β-xylanase (XY) exert positive effects on growth performance, nutrient digestibility, meat quality, fecal microflora, and fecal gas emission.

Materials and Methods

The experimental protocol used in this study was approved by the Animal Care and Use Committee of Dankook University, South Korea.

Source of EF and XY

The probiotic product (Bonvital®) used in our study was provided by a commercial company (Schaumann Agri International GmbH, Pinneberg, Germany). This product is composed of spray-dried spore-forming EF, which is guaranteed to contain at least 1.0×10^{10} cfu g^{-1} of live EF DSM 7134.

The enzyme preparation used in this study is Nutrase Xyla (Nutrex Nv, Lille, Belgium) and the producing microorganism is *Bacillus subtilis*. It is a specific XY (IUB: EC 3.2.1.8; 9000 U g^{-1}) with an optimal activity at neutral pH.

Experimental design, animals, and diets

A total of 128 [(Landrace × Yorkshire) × Duroc] pigs with an average body weight (BW) of 49.9 ± 2.80 kg were used in a 12 wk trial. Pigs were allocated randomly into one of four treatments in a 2 × 2 factorial arrangement with two levels of EF (0 and 0.1 g kg^{-1} diet) and XY (0 and 0.1 g kg^{-1} diet) according to sex and BW (eight replicates with two gilts and two barrows per pen). The diets were formulated to meet or exceed NRC (2012) nutrient requirements (Table 1). Pigs were housed in an environmentally controlled, slatted plastic floor facility in 32 adjacent pens (1.8 m × 1.8 m each). Each pen was equipped with a self feeder and nipple drinker to allow ad libitum access to feed and water throughout the experimental period. Room temperature and humidity were maintained at 25 °C and 60%, respectively.

Sampling and measurements

Pig BW and feed intake were measured initially and at the end of week 6, week 9, and week 12 of the experimental period and feed consumption was recorded on a pen basis during the experiment to determine average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F).

Chromium oxide was added to the diet as an indigestible marker at 0.20% of the diet for seven days prior to fecal collection at the 6th and 12th weeks for calculation of dry matter (DM), nitrogen (N), and energy digestibility. Fecal grab samples were collected at random from at least two pigs in each pen (one gilt and one barrow). All feed and feces samples were stored immediately at −20 °C until analysis. Fecal samples were dried at 70 °C for 72 h and finely ground to pass through a 1 mm screen. The procedures used for the determination of DM, N, and energy digestibility were in accordance with the methods established by the Association of Official Analytical Chemists (AOAC 2002). Chromium concentrations were determined via UV absorption spectrophotometry (UV-1201, Shimadzu, Kyoto, Japan) and the apparent total tract digestibility (ATTD) of DM, N, and energy were calculated using indirect methods, as described by Fenton and Fenton (1979). The digestibility (%) was calculated using the following formula:

$$\text{Digestibility} = \{1 - [(\text{Nf} \times \text{Cd})/(\text{Nd} \times \text{Cf})]\} \times 100$$

Table 1. Basal diet composition (as-fed basis).

Items	%
Ingredients	
Corn	66.00
Soybean meal (CP 47.5%)	23.96
Animal fat	4.24
Molasses	3.00
Dicalcium phosphate	1.26
Salt	0.25
Limestone	1.01
Vitamin premix[a]	0.12
Trace mineral premix[b]	0.10
Ethoxyquin	0.05
L-Lysine-HCL	0.01
Chemical composition[c]	
ME (kcal kg^{-1})	3350
CP (%)	18.00
Lys (%)	0.90
Met (%)	0.28
Ca (%)	0.70
P (%)	0.60
Analyzed composition	
GE (kcal kg^{-1})	4105
CP (g kg^{-1})	17.53
Ca (g kg^{-1})	0.71
P (g kg^{-1})	0.59

Note: CP, crude protein; ME, metabolizable energy; GE, gross energy.

[a]Provided per kilogram of complete diet: 4800 IU vitamin A, 960 IU vitamin D_3, 20 IU vitamin E, 2.4 mg vitamin K_3, 4.6 mg vitamin B_2, 1.2 mg vitamin B_6, 13 mg pantothenic acid, 23.5 mg niacin, and 0.02 mg biotin.

[b]Provided per kilogram of complete diet: 12.5 mg Mn, 179 mg Zn, 5 mg Cu, 0.5 mg I, and 0.4 mg Se.

[c]Calculated based on the composition value of NRC (2012).

where Nf is the nutrient concentration in faeces (% DM), Nd is the nutrient concentration in diet (% DM), Cf is the chromium concentration in faeces (% DM), and Cd is the chromium concentration in diet (% DM).

At the end of 6th and 12th weeks, fecal samples were collected directly via massaging the rectum of two pigs (one gilt and one barrow) in each pen and then pooled and placed on ice for transportation to the laboratory where analysis was immediately performed. A calibrated, glass-electrode pH meter (WTW pH 340-A; WTH Measurement Systems Inc., Ft. Myers, FL, USA) was used to measure the pH of the fecal samples, which were diluted with deionized water at a ratio of 1:7.5 (*w*/*w*). One gram of the composite fecal sample from each pen was diluted with 9 mL of 1% peptone broth (Becton, Dickinson and Co., Franklin Lakes, NJ, USA) and then homogenized. Viable counts of bacteria in the fecal samples were then conducted by plating serial 10-fold dilutions (in 1% peptone solution) onto MacConkey agar plates (Difco Laboratories, Detroit, MI, USA) and *Lactobacilli* medium III agar plates (Medium 638; DSMZ, Braunschweig, Germany) to isolate the *E. coli* and *Lactobacillus*, respectively. The *Lactobacilli* medium III agar plates were then incubated for 48 h at 39 °C under anaerobic conditions. The MacConkey agar plates were incubated for 24 h at 37 °C. The *E. coli* and *Lactobacillus* colonies were counted immediately after removal from the incubator.

Fresh feces and urine samples were collected randomly from at least two pigs in each pen on the last 2 d of the end of 6th and 12th weeks. The urine was collected in a bucket via a funnel below the cage. Samples were kept in sealed containers and were immediately stored at −4 °C for the duration of the period. After the collection period, feces and urine samples were pooled and each mixed well for each pen. As described by Y. Wang et al. (2009), subsamples of slurry (150 g feces and 150 g of urine were mixed well; 1:1 on the wet weight basis) were taken and stored in 2.6 L plastic boxes in duplicate. Each box had a small hole in the middle of one side wall, which was sealed with adhesive plaster. The samples were permitted to ferment for 7 d at room temperature (25 °C). The concentrations of gas were determined on day 7. A gas sampling pump (Model GV-100; Gastec Corp., Ayase, Japan) was utilized for gas detection [Gastec detector tube No. 3La for ammoniac (NH_3), No. 4LK for hydrogen sulfide (H_2S), and No. 70 for mercaptans; Gastec Corp.]. Before the measurements, slurry samples were shaken manually for approximately 30 s to disrupt any crust formation on the surface of the slurry sample and to homogenize them. The adhesive plasters were punctured, and 100 mL of headspace air was sampled approximately 2.0 cm above the slurry surface. Two samples from each pen were measured and then the average was calculated.

At the end of the experiment, all the pigs were slaughtered at a local commercial facility. Carcasses were chilled at 2 °C for 24 h and a sample of the right loin was removed between the 10th and 11th ribs. Subjective meat color, marbling, and firmness scores were evaluated [National Pork Production Council (NPPC 1991)]. Immediately after the subjective scores were determined, the lightness (L^*), redness (a^*), and yellowness (b^*) values were measured at three locations on the surface of each sample (Model CR-410 Chromameter; Konica Minolta Sensing Inc., Osaka, Japan). At the same time, duplicate pH values of each sample were directly measured using a pH meter (Fisher Scientific, Pittsburgh, PA, USA). The water-holding capacity (WHC) was measured in accordance with the methods described by Kauffman et al. (1986). Briefly, a 0.3 g sample was pressed at 3000 psi for 3 min at 26 °C on a 125 mm-diameter piece of filter paper. The areas of the pressed

Table 2. Effects of probiotic and xylanase supplementation on growth performance in finishing pigs.

	−EF		+EF			*P* value		
Item	−XY	+XY	−XY	+XY	SEM	EF	XY	EF × XY
BW (kg)								
Initial	49.89	49.95	49.93	49.84	1.106	0.969	0.990	0.959
Week 6	80.32	81.07	81.74	82.59	1.526	0.345	0.605	0.978
Week 9	97.08	98.90	99.58	100.91	1.821	0.227	0.397	0.895
Week 12	114.53	117.05	117.61	119.46	2.112	0.205	0.312	0.870
0–6 (wk)								
ADG (g)	724	741	757	776	14.53	0.029	0.246	0.961
ADFI (g)	2322	2311	2325	2335	65.67	0.836	0.998	0.874
G:F	0.313	0.323	0.327	0.332	0.007	0.082	0.248	0.723
6–9 (wk)								
ADG (g)	798	849	850	872	17.48	0.043	0.045	0.424
ADFI (g)	2649	2637	2623	2690	42.57	0.748	0.519	0.364
G:F	0.301	0.322	0.324	0.324	0.006	0.036	0.068	0.075
9–12 (wk)								
ADG (g)	831	864	858	883	16.53	0.173	0.093	0.801
ADFI (g)	2859	2872	2896	2899	64.27	0.621	0.905	0.941
G:F	0.291	0.302	0.296	0.305	0.005	0.377	0.076	0.834
0–12 (wk)								
ADG (g)	770	799	803	827	14.55	0.038	0.096	0.746
ADFI (g)	2538	2533	2542	2573	48.06	0.643	0.791	0.709
G:F	0.303	0.316	0.317	0.321	0.004	0.033	0.048	0.319

Note: There were eight replicate pens per treatment with four pigs per pen. EF, *Enterococcus faecium*; XY, endo-1,4-β-xylanase; + or −, supplemented with or without 0.1 g kg^{-1} EF and 0.1 g kg^{-1} XY, respectively; SEM, standard error of the mean; BW, body weight; ADG, average daily gain; ADFI, average daily feed intake; G:F, gain to feed ratio.

sample and the expressed moisture were delineated and then determined using a digitizing area-line sensor (MT-10S; M.T. Precision Co. Ltd., Tokyo, Japan). The ratio of water:meat area was then calculated, giving a measure of WHC (a smaller ratio indicates increased WHC). Longissimus muscle area (LMA) was measured by tracing the LM surface at the 10th rib, which was also conducted using the aforementioned digitizing area-line sensor. Drip loss was measured using approximately 2 g of meat sample and the plastic bag method described by Honikel (1998). Cook loss was determined as described previously by Sullivan et al. (2007).

Statistical analysis

The pen was used as the experiment unit and all data were analyzed as a randomized block design according to their initial BW and group of pigs allotted as blocking factor, with a 2 × 2 factorial arrangement, using GLM procedure (SAS Institute Inc., Cary, NC, USA). The model utilized included the effects of EF and XY, as well as the interaction. When a significant interaction was observed, the means of each treatment were compared using Fisher's protected least significant difference. Variability in the data was expressed as the pooled standard error, and a probability level of $P < 0.05$ was considered to be statistically significant.

Results

Growth performance

In the current study, pigs fed the diets with EF supplementation increased ($P < 0.05$) the ADG for week 0–6, week 6–9, and week 0–12 compared with pigs fed the diets without EF supplementation (Table 2). In addition, the G:F of pigs fed the diets with EF supplementation increased ($P < 0.05$) compared with the diets without EF supplementation for week 6–9 and week 0–12. Additionally, pigs fed the diets with XY supplementation had higher ($P < 0.05$) ADG for week 6–9 and G:F for week 0–12 than those fed with the diets without XY supplementation. However, during week 9–12, no differences ($P > 0.05$) were observed in ADG, ADFI, and G:F, as well as BW, during the whole experimental period of pigs fed with the diets with EF or XY supplementation, compared with those fed the diets without EF or XY supplementation.

Table 3. Effects of probiotic and xylanase supplementation on nutrient digestibility in finishing pigs.

	−EF		+EF			*P* value		
Item	−XY	+XY	−XY	+XY	SEM	EF	XY	EF × XY
Week 6								
Dry matter	76.74	79.86	80.51	81.48	1.023	0.012	0.049	0.303
Nitrogen	77.79	80.36	81.23	82.12	1.097	0.025	0.127	0.450
Energy	75.7	78.12	79.08	80.43	1.032	0.010	0.079	0.610
Week 12								
Dry matter	74.17	75.42	75.02	78.33	1.200	0.129	0.068	0.400
Nitrogen	75.05	76.44	76.17	78.62	1.714	0.343	0.273	0.761
Energy	73.19	74.26	74.12	76.19	2.065	0.493	0.453	0.810

Note: There were eight replicate pens per treatment with four pigs per pen.
EF, *Enterococcus faecium*; XY, endo-1,4-β-xylanase; + or −, supplemented with or without 0.1 g kg^{-1} EF and 0.1 g kg^{-1} XY, respectively; SEM, standard error of the mean.

Table 4. Effects of probiotic and xylanase supplementation on fecal microflora in finishing pigs.

	−EF		+EF			*P* value		
Item (log_{10} cfu g^{-1})	−XY	+XY	−XY	+XY	SEM	EF	XY	EF × XY
Week 6								
Lactobacillus	6.96	7.32	7.46	7.73	0.153	0.024	0.030	0.702
Escherichia coli	6.20	5.50	5.47	5.28	0.161	0.012	0.017	0.137
Week 12								
Lactobacillus	7.21	7.54	7.68	7.71	0.182	0.103	0.346	0.430
Escherichia coli	6.26	5.49	5.70	5.20	0.175	0.032	0.003	0.455

Note: There were eight replicate pens per treatment with four pigs per pen. EF, *Enterococcus faecium*; XY, endo-1,4-β-xylanase; + or −, supplemented with or without 0.1 g kg^{-1} EF and 0.1 g kg^{-1} XY, respectively; SEM, standard error of the mean.

Nutrient digestibility

Pigs fed the diets with EF supplementation increased ($P < 0.05$) the ATTD of DM, N, and energy at the 6th week compared with pigs fed the diets without EF supplementation (Table 3). The ATTD of DM of pigs fed the diets with XY supplementation was greater ($P < 0.05$) than the ATTD of DM of pigs fed the diets without XY supplementation at the 6th week. No differences ($P > 0.05$) were observed in the ATTTD of DM, N, and energy of pigs fed EF or XY supplementation compared with those fed the diets without EF or XY supplementation at the 12th week.

Fecal microflora

Dietary EF or XY supplementation led to higher ($P < 0.05$) counts of *Lactobacillus*, and lower ($P < 0.05$) counts of *E. coli* than the diets without EF or XY supplementation at the 6th week (Table 4). At the 12th week, pigs fed the diets with EF or XY supplementation decreased ($P < 0.05$) the fecal *E. coli* concentration compared with the diets without EF or XY supplementation. However, no difference ($P > 0.05$) was observed on the fecal *Lactobacillus* concentration at the 12th week.

Fecal noxious gas content

Dietary supplementation of EF or XY (0.1 g kg^{-1} of feed) failed to show significant effect on fecal noxious gas content ($P > 0.05$) (Table 5).

Meat quality

Supplementation of EF or XY (0.1 g kg^{-1} of feed) had no effect in pH, LMA, WHC, meat color, cooking loss, sensory evaluation (color, marbling, and firmness), and drip loss on day 1, day 3, day 5, and day 7 on meat quality in finishing pigs ($P > 0.05$) (Table 6).

No interactions between EF and XY on growth performance, nutrient digestibility, fecal microflora, fecal noxious gas emission, and meat quality were detected ($P > 0.05$).

Discussion

Effects of EF

Growth performance and nutrient digestibility

In this study, the ADG and G:F improved in pigs fed the EF supplemented diets, which was in agreement with Mohana Devi and Kim (2014) and Zhang et al. (2014), who suggested that weaned pigs fed dietary EF DSM 7134 increased ADG, and decreased the feed

Table 5. Effects of probiotic and xylanase supplementation on fecal gas emission in finishing pigs.

	−EF		+EF			*P* value		
Item (ppm)	−XY	+XY	−XY	+XY	SEM	EF	XY	EF × XY
Week 6								
NH_3	5.6	5.3	5.3	5.2	0.739	0.766	0.843	0.921
R.SH	7.7	7.3	7.3	6.9	0.396	0.378	0.318	0.975
H_2S	4.5	4.2	4.1	3.8	0.577	0.528	0.556	0.966
Week 12								
NH_3	5.3	5.2	5.1	5.0	0.731	0.789	0.867	1.000
R.SH	7.5	7.1	7.2	6.8	0.413	0.446	0.381	0.906
H_2S	4.4	4.0	3.9	3.7	0.566	0.493	0.606	0.863

Note: There were eight replicate pens per treatment with four pigs per pen. EF, *Enterococcus faecium*; XY, endo-1,4-β-xylanase; + or −, supplemented with or without 0.1 g kg^{-1} EF and 0.1 g kg^{-1} XY, respectively; NH_3, ammonia; R.SH, total mercaptans; H_2S, hydrogen sulfide; SEM, standard error of the mean.

Table 6. Effects of probiotic and xylanase supplementation on meat quality in finishing pigs.

	−EF		+EF			*P* value		
Item	−XY	+XY	−XY	+XY	SEM	EF	XY	EF × XY
pH	5.67	5.56	5.59	5.61	0.088	0.857	0.629	0.501
LMA (cm^2)	50.63	50.74	50.94	50.93	0.629	0.700	0.937	0.924
WHC (%)	50.62	50.72	50.31	50.34	1.853	0.854	0.970	0.984
Meat color								
L^*	54.50	55.53	56.19	56.96	0.929	0.119	0.352	0.889
a^*	16.43	16.12	16.14	16.43	0.434	0.980	0.975	0.498
b^*	5.79	5.24	5.82	5.75	0.231	0.263	0.203	0.317
Cooking loss (%)	40.97	39.62	40.73	39.37	0.98	0.809	0.200	0.996
Sensory evaluation								
Color	3.10	3.55	3.65	3.40	0.252	0.444	0.699	0.191
Marbling	3.25	3.30	3.08	3.00	0.113	0.058	0.914	0.592
Firmness	3.10	3.35	3.30	3.45	0.114	0.212	0.104	0.668
Drip loss (%)								
*d*1	6.40	6.43	6.78	6.02	0.320	0.976	0.276	0.235
*d*3	14.17	14.03	13.76	13.55	0.48	0.379	0.720	0.945
*d*5	23.02	22.36	19.83	20.97	1.438	0.137	0.870	0.543
*d*7	25.58	24.39	22.97	22.85	1.352	0.151	0.636	0.699

Note: There were eight replicate pens per treatment with four pigs per pen. EF, *Enterococcus faecium*; XY, endo-1,4-β-xylanase; + or −, supplemented with or without 0.1 g kg^{-1} EF and 0.1 g kg^{-1} XY, respectively; LMA, longissimus muscle area; WHC, water-holding capacity; L^*, lightness; a^*, redness; b^*, yellowness; SEM, standard error of the mean.

conversion ratio compared with control treatment. Chen et al. (2006) reported that the inclusion of EF SF68 (0, 0.175, and 0.350×10^9 cfu kg^{-1} diet) leads to linearly increased ADG during weeks 4–8 in finishing pigs. Additionally, in this study, dietary EF supplementation (0.1 g kg^{-1}) increased the ATTD of DM, N, and energy. Our results are in agreement with Yan and Kim (2013), who reported that the ATTD was increased by administration EF DSM 7134 at the dosage of 2.0×10^9 cfu kg^{-1} diet in finishing pigs. Chen et al. (2006) found that dietary EF SF68 (0, 0.175, and 0.350×10^9 cfu kg^{-1} diet) linearly increased the ATTD of DM and N in finishing pigs. Zhang et al. (2014) also indicated that the digestibility of N and energy was improved in pigs fed the EF (1.0×10^9 cfu kg^{-1} diet) supplemented diet. de Vrese and Marteau (2007) reported that microflora in the gastrointestinal tract play a crucial role in anatomical, physiological, and immunological organ development of the host animals. Therefore, the improved nutrient digestibility and growth performance in our study were probably due to the improved ecosystem (increased *Lactobacillus* number and decreased *E. coli* population).

Fecal microflora

In our study, the probiotic supplementation in the diets significantly increased the fecal *Lactobacillus* concentration and decreased the fecal *E. coli* concentration. Similar results were also reported by other researchers, Yan and Kim (2013) and Zhang et al. (2014) shown that the fecal *Lactobacillus* was increased by the dietary EF supplementation, which is in accordance with Zhang and Kim (2015), who suggested that the ileal and fecal *Lactobacilli* counts of pigs fed the EF diets were increased by 19.9% and 16.6%, and *E. coli* counts were decreased by 8.9% and 9.5%, respectively. Likewise, Mallo et al. (2010) also reported that EF CECT 4515 (10^6 cfu g^{-1}) of diet increased the *Lactobacilli* in the ileum. Černauskienė et al. (2011) suggested that EF is a normal microorganism in swine intestine, which could produce lactic acid to reduce the pH value of the intestinal ontent, and inhibit the development of invasive pathogens, which could be the possible reason for the current results.

Fecal noxious gas content

In this study, dietary supplementation of EF (0.1 g kg^{-1} of feed) failed to affect fecal noxious gas content, which is in agreement with Mohana Devi and Kim (2014), who suggested that supplementation with dietary EF did not result in any reduction in total mercaptans, H_2S, and NH_3 in weanling pigs. However, these results are contrary to the findings of Yan and Kim (2013), who reported that fecal noxious gas content reduced after probiotic supplementation in growing pigs. Zhang et al. (2014) also reported that fecal NH_3 contents were reduced in weanling pigs fed 1×10^9 cfu kg^{-1} of EF administration. Broom et al. (2006) suggested that the efficiency of probiotics may be higher when animals are confronted with challenge or stress; however, there is no challenge or stress on pigs in our study.

Effects of XY

Growth performance and nutrient digestibility

In this study, pigs fed xylanase supplementation diets had better ADG and G:F than those fed the diets without xylanase supplementation. In agreement with our findings, Fang et al. (2007) and Barrera et al. (2004) reported that dietary xylanase supplementation had a positive effect on ADG and G:F in growing pigs fed corn-, soybean-, and rapeseed-based diets. Likewise, our previous study detected that the xylanase supplementation (0.5 and 1 g kg^{-1}) linearly increased ($P < 0.05$) ADG, and G:F ratio of weaning pigs (Lan et al. 2017). However, these results are contrary to the findings of Olukosi et al. (2007), who reported that no effects of xylanase (in units kg^{-1}) at 400, 800, 1 600, 3 200, or 32 000 supplementation to diets composed of corn, rye, wheat, and soybean meals were observed on any of the growth performance responses of the 10 kg pigs. Additionally, in this study, xylanase supplementation showed an increase in DM digestibility compared with those fed diets without xylanase supplementation, and the energy digestibility tended to increase ($P = 0.079$) in pigs fed diets with xylanase supplementation during week 6. Similar results were also reported by other researchers. For instance, Passos et al. (2015) and Lan et al. (2017), who reported that the supplementation of xylanase diets based on corn–soybean meal improved ileal digestibility of DM and energy in pigs. The xylanase supplementation hydrolyses arabinoxylans in corn, thus enabling endogenous digestive enzymes to access trapped nutrients (Adeola and Cowieson 2011). According to Olukosi et al. (2007), xylanase reduces the length and hence, the structural integrity of xylan molecules, thus providing easier access for enzymes to their substrates, and this may improve nutrient digestibility. The improvement in ATTD of DM and GE with xylanase supplementation can, in turn, induce a significant increase in the ADG and G:F in this study.

Fecal microflora

Our results revealed that XY supplementation in the diets led to significantly higher counts of *Lactobacillus* and lower counts of *E. coli*. In agreement with our results, Yi et al. (2013) reported that enzyme supplementation significantly increased the population of *Lactobacilli* in the cecum. In the colon, the population of *E. coli* was lower for pigs fed the diets supplemented with enzyme than those without enzyme supplementation. A study by Saha (2001) reported that arabinose and xylose, which is a product of xylanase hydrolysis, can positively affect lactic acid bacterial activity. Thus, we assume that the increased *Lactobacillus* count and reduced *E. coli* count in the current study could be due to the hydrolysis product of xylanase.

Fecal noxious gas content

Fecal noxious gas emission such as NH_3-N, H_2S, and volatile fatty acid has become one of the major air pollution in modern concentrative pig production (Slanina 1994). Therefore, fecal noxious gas emission is of great concern to the public. Lan et al. (2017) reported that there were linear decreases in fecal NH_3 and H_2S emissions with dietary xylanase supplementation in weanling pigs fed diets based on corn–soybean meal. However, in this study, dietary supplementation of xylanase (0.1 g kg^{-1} of feed) failed to demonstrate any effect on fecal noxious gas content. Similarly, Guo et al. (2011) reported that no effects in fecal H_2S, acetic acid, and NH_3 gas emission concentrations were observed in growing pigs fed different percentage of enzyme (protease, amylase, xylanase, cellulase, and alpha-galactosidase) fermented oat or wheat diets. As the diets in our study were based on corn, which has a quite low non-starch polysaccharides content, that could be a reason to explain our results.

Meat quality

Our study has shown that supplementation of EF or XY (0.1 g kg^{-1} of feed) had no effect on meat quality in finishing pigs. Similarly, Černauskienė et al. (2011) reported that no effects in cooking loss and WHC were detected in finishing pig fed the dietary supplementation of EF. Cho and Kim (2013) and J.P. Wang et al. (2009) also reported that the inclusion of the enzyme did not affect the meat quality (drip loss, cooking loss, pH, meat color, and WHC). However, the results are not always consistent. Meng et al. (2010) reported that pigs fed diets with probiotics improved the color scores and redness values and decreased the marbling and lightness. In addition, pigs fed the diets with xylanase significantly reduced drip loss percentage on day 7 and increased the redness value. However, the influence of EF or XY on the meat quality remains poorly evidenced in literature. The reason for the difference is unknown, because according to D'Alessandro and Zolla (2013) who reported that meat quality is affected by lots of factors, including breed, nutrition, husbandry conditions, and handling before and after slaughter. Therefore, further experiments are necessary to be conducted to assess the influence of EF or XY supplementation on carcass quality in finishing pigs.

Conclusion

In conclusion, dietary supplementation of EF or XY increased growth performance throughout the experimental period, improved ATTD of DM at the 6th week, as well as fecal *Lactobacillus* concentration, and decreased the fecal *E. coli* concentration in finishing pigs at the 6th and 12th weeks. No difference was observed on meat quality and fecal gas emission in this study. No interactive effect in all parameters except for a trend in G:F ratio during week 6–9 was observed between EF or XY inclusion. Further research is needed to determine the optimal amount of EF and XY supplementation in combination in finishing pigs.

Competing Interests

The authors declare that they have no competing interests.

Authors' Contribution

All authors read and approved the final manuscript.

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