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ARTICLE

Effects of a blend of organic acids and medium-chain fatty acids with and without *Enterococcus faecium* on growth performance, nutrient digestibility, blood parameters, and meat quality in finishing pigs

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Abstract: An experiment was conducted to assess effects of *Enterococcus faecium* and a blend of organic acids (OAs) and medium-chain fatty acids (MCFAs) in finishing pigs. A total of 120 pigs [Duroc × (Yorkshire × Landrace); 51.04 ± 1.82 kg] were randomly assigned to five dietary treatments: CON, basal diet; BOM1, CON + 500 mg kg^{-1} blend of OAs and MCFAs; BOM2, CON + 1000 mg kg^{-1} blend of OAs and MCFAs; EBOM1, BOM1 + 20 mg kg^{-1} *E. faecium*; EBOM2, BOM2 + 20 mg kg^{-1} *E. faecium*. Pigs fed EBOM1 and EBOM2 diets had higher average daily gain and average daily feed intake (during days 36–70 and days 1–70) and greater digestibility of dry matter (days 35 and 70) compared with those fed BOM1 and BOM2 diets ($P < 0.05$). However, no differences on blood parameters and meat quality were observed between pigs offered BOM1 and BOM2 diets and those fed EBOM1 and EBOM2 diets ($P > 0.05$). In conclusion, supplementation with the combination of *E. faecium* and a blend of OAs and MCFAs was more effective in improving growth performance and nutrient digestibility than supplementation with blend of OAs and MCFAs alone in finishing pigs.

Key words: Enterococcus faecium, pigs, growth performance, nutrient digestibility, organic acids.

Résumé : Une expérience a été effectuée pour évaluer les effets d'*Enterococcus faecium* et d'un mélange d'acides organiques (OAs — « organic acids ») et d'acides gras à chaînes moyennes (MCFAs — « medium-chain fatty acids ») chez les porcs en finition. Un total de 120 porcs [Duroc × (Yorkshire × Landrace); 51,04 ± 1,82 kg] ont été assignés aléatoirement à cinq traitements alimentaires : CON, la diète de base; BOM1, la diète CON + 500 mg kg^{-1} de mélange d'OAs et de MCFAs; BOM2, la diète CON + 1000 mg kg^{-1} de mélange d'OAs et de MCFAs; EBOM1, la diète BOM1 + 20 mg kg^{-1} d'*E. faecium*; EBOM2, la diète BOM2 + 20 mg kg^{-1} d'*E. faecium*. Les porcs ayant reçu les diètes EBOM1 et EBOM2 ont montré de plus grands gains moyens quotidiens et de plus grandes consommations moyennes quotidiennes (durant les jours 36 à 70 ainsi que 1 à 70) et une plus grande digestibilité des matières sèches (jours 35 et 70) par rapport à ceux ayant reçu les diètes BOM1 et BOM2 ($P < 0,05$). Par contre, aucune différence sur les paramètres sanguins ni la qualité de viande n'ont été observées entre les porcs ayant reçu les diètes BOM1 et BOM2 et ceux ayant reçu les diètes EBOM1 et EBOM2 ($P > 0,05$). En conclusion, la supplémentation avec une combinaison d'*E. faecium* et un mélange d'OAs et de MCFAs était plus efficace pour améliorer la performance de croissance et la digestibilité des éléments nutritifs que la supplémentation avec un mélange d'OAs et de MCFAs seuls chez les porcs en finition. [Traduit par la Rédaction]

Mots-clés : Enterococcus faecium, porcs, performance de croissance, digestibilité des éléments nutritifs, acides organiques.

Introduction

Antibiotic growth promoters have been widely used in animal feeds to improve growth performance and maintain animal health (Brown et al. 2017). However, many countries gradually banned all antibiotic growth promoters in animal feed due to public health concerns

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regarding the potential for the emergency of antimicrobial resistance from the use of the antibiotic growth promoters (Casewell et al. 2003; Heo et al. 2013). In this context, therefore, there is growing interest to explore alternatives to antibiotic growth promoters to enhance growth performance and maintain the health status of animals. Organic acids (OAs), medium-chain fatty acids (MCFAs), and probiotics have been studied in diets of pigs (Zhao et al. 2013).

As desirable alternatives to antibiotic growth promoters, OAs have been widely used in swine diets. Although OA supplementation was initially targeted for nursery pigs, there is growing evidence showing that supplementation of OAs may also exert beneficial effects in finishing pigs (Murphy et al. 2010; Upadhaya et al. 2014*b*). In addition, it has been demonstrated that OAs can be effectively combined with other feed additives (Suiryanrayna and Ramana 2015). Recent studies have shown that dietary supplementation with the combination of OAs and MCFAs can improve growth performance, nutrient digestibility, or meat quality in weanling or finishing pigs (Upadhaya et al. 2014*b*; Kuang et al. 2015; Lei et al. 2017).

Probiotics have been suggested as alternatives to antibiotic growth promoters that can affect the host by improving its intestinal microbial balance (Fuller 1989). The most commonly used probiotic species are lactic acid bacteria, such as *Lactobacillus*, *Bifidobacteria*, *Streptococcus*, and *Enterococcus* (Land et al. 2005; Gaggìa et al. 2010). Previous studies have demonstrated that dietary administration of *Enterococcus faecium* can improve growth performance and nutrient digestibility in pigs (Chen et al. 2006; Malloa et al. 2010; Zhang and Kim 2015). We hypothesized that dietary supplementation with *E. faecium* and blend of OAs and MCFAs may exert better beneficial effects in finishing pigs compared with supplementation of the blend of OAs and MCFAs alone.

Therefore, the objective of the present study was to investigate the effects of dietary supplementation with a blend of OAs and MCFAs with and without *E. faecium* DSM 7134 on growth performance, nutrient digestibility, blood parameters, and meat quality in finishing pigs.

Material and Methods

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

Source of *E. faecium* and the blend of OAs and MCFAs

The blend of OAs and MCFAs used in the experiment was provided by a commercial company (Morningbio Co., Ltd., Cheonan, South Korea). The active ingredients were 170 g kg^{-1} fumaric acid, 130 g kg^{-1} citric acid, 100 g kg^{-1} malic acid, and 12 g kg^{-1} MCFAs (capric and caprylic acid, provided as 1:1 mixture product).

Enterococcus faecium used in our study was provided by a commercial company (Schaumann Agri International GmbH, Pinneberg, Germany). This product was guaranteed to contain at least 1.0×10^{10} cfu g^{-1} of *E. faecium* DSM 7134.

Experimental design, animals, and housing

A total of 120 finishing pigs [Duroc × (Yorkshire × Landrace)] with an average initial body weight (BW) of 51.04 ± 1.82 kg were randomly allotted into one of five experimental diets according to initial BW and sex (six replicate pens per treatment; two gilts and two barrows per pen) in this 70 d feeding study. Dietary treatments included: (1) control, basal diet (CON); (2) basal diet supplemented with 500 mg kg^{-1} blend of OAs and MCFAs (BOM1); (3) basal diet supplemented with 1000 mg kg^{-1} blend of OAs and MCFAs (BOM2); (4) basal diet supplemented with 20 mg kg^{-1} *E. faecium* DSM 7134 and 500 mg kg^{-1} blend of OAs and MCFAs (EBOM1); and (5) basal diet supplemented with 20 mg kg^{-1} *E. faecium* DSM 7134 and 1000 mg kg^{-1} blend of OAs and MCFAs (EBOM2). The supplemental doses of *E. faecium* DSM 7134 and the blend of OAs and MCFAs were modified based on the results of previous studies (Upadhaya et al. 2014*a*; Zhang and Kim 2015). All diets were formulated to meet or exceed the nutrient requirements established by the NRC (2012). The composition and nutrient contents of basal diets are presented in Table 1. Diets were fed in two phases including days 1–35 and days 36–70. All pigs were housed in an environmentally controlled room with slatted plastic floor facility. The room temperature was maintained at approximately 24 °C. Each pen was equipped with a self-feeder and a nipple drinker to allow ad libitum access to feed and water throughout the experimental period.

Sampling and measurements

Individual pig BW was recorded at the beginning, middle, and end of the experiment. Feed consumption was recorded on a pen basis during the experiment to calculate average daily gain (ADG), average daily feed intake (ADFI), and gain:feed ratio (G:F).

Pigs were fed diets mixed with chromic oxide (2 g kg^{-1}) as an indigestible marker for the determination of the apparent total tract digestibility (ATTD) of dry matter (DM) and nitrogen (N) from days 29 to 35 and days 64 to 70. On days 35 and 70, fecal samples were collected from all pens via rectal massage. Fecal samples from the same pen were pooled and mixed immediately, after which samples were stored at −20 °C until subsequent analysis were conducted. For chemical analysis, fecal samples were oven-dried at 60 °C for 72 h, after which diets and feces were ground to pass through a

Table 1. Composition and nutrient level of the basal diet (as-fed basis).

Item	Days 1–35	Days 36–70
Ingredients (g kg^{-1})		
Corn	450.6	511.5
wheat	130.0	130.0
Soybean meal	230.0	187.0
Rapeseed meal	22.0	—
Corn-DDGS	50.0	60.0
Animal fat	53.0	48.6
Molasses	32.0	30.0
Dicalcium phosphate	10.6	11.2
Limestone	10.0	9.5
Salt	3.0	3.0
L-Lysine-sulfate	2.4	3.2
DL-Methionine	1.2	1.8
L-Tryptophan	0.1	—
L-Threonine	1.3	0.7
Choline chloride	0.8	0.5
Vitamin premix[a]	1.5	1.5
Mineral premix[b]	1.5	1.5
Calculated composition (kcal kg^{-1})		
Metabolizable energy	3400	3400
Analyzed composition (g kg^{-1})		
Crude protein	176.4	154.9
Lysine	9.3	9.0
Methionine	3.1	3.0
Calcium	7.6	7.3
Total phosphorus	5.8	5.8

[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 riboflavin, 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 manganese (as MnO_2), 179 mg zinc (as $ZnSO_4$), 5 mg copper (as $CuSO_4 \cdot 5H_2O$), 0.5 mg iodine (as KI), 0.4 mg selenium (as $Na_2SeO_3 \cdot 5H_2O$), and 75 mg iron (as $FeSO_4 \cdot 7H_2O$).

1.0 mm screen for analysis of DM (method 930.15) and N (method 984.13) using the AOAC (2007) procedures. Chromium was analyzed via UV absorption spectrophotometry (UV-1201, Shimadzu Corp., Kyoto, Japan), according to the method described by Williams et al. (1962). The ATTD was then calculated using the following formula: ATTD (%) = $[1 - \{(Nf \times Cd)/(Nd \times Cf)\}] \times 100$, where Nf is the nutrient concentration in feces (% DM), Nd is the nutrient concentration in diet (% DM), Cd is the chromium concentration in diet (% DM), and Cf is the chromium concentration in feces (% DM).

For serum analysis, on days 35 and 70, the blood samples were collected from two pigs (one gilt and one barrow) per pen and centrifuged (3000*g*) for 15 min at 4 °C to obtain the serum samples. The serum samples were analyzed to determine the concentrations of blood urea nitrogen (BUN), creatinine, alanine aminotransferase (ALT), aspartate aminotransferase (AST), high-density lipoprotein cholesterol (HDL-C), and low-density lipoprotein cholesterol (LDL-C) with an automatic Biochemical Analyzer (HITACHI 747, Tokyo, Japan).

At the end of the experiment, all the pigs were slaughtered at a local commercial slaughterhouse. Carcasses were chilled at 2 °C for 24 h, and a sample of the right loin was removed between the 10th and 11th ribs. The meat samples were thawed at room temperature before evaluation. Subjective meat color, marbling, and firmness scores were evaluated according to NPPC (1991) standards. Immediately after the subjective tests were conducted, the lightness (L^*), redness (a^*), and yellowness (b^*) values were measured at three locations on the surface of each sample using a Chroma meter (model CR-410, 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 of sample was pressed at 3000*g* for 3 min at 26 °C on a 125 mm diameter piece of filter paper. The areas of the pressed 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 (LM) area 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 according to the plastic bag method described by Honikel (1998). Cooking loss was determined as described previously by Sullivan et al. (2007).

Statistical analysis

All experimental data were analyzed as a randomized complete block design using the GLM procedure of SAS version 9.2 (SAS Institute Inc., Cary, NC, USA). The pen was used as the experimental unit. Orthogonal contrasts were used to the effect of treatments: CON vs. BOM1 + BOM2; CON vs. EBOM1 + EBOM2; BOM1 + BOM2 vs. EBOM1 + EBOM2; BOM1 vs. BOM2; and EBOM1 vs. EBOM2 treatments. Variability in the data was expressed as the standard error of the mean. A probability level of $P < 0.05$ was considered statistically significant.

Results

Growth performance

Throughout the experiment, supplementation with blend of OAs and MCFAs improved ($P < 0.05$) G:F compared with CON treatment, although ADG and ADFI were not affected ($P > 0.05$; Table 2). However, no significant differences were observed on ADG, ADFI, or G:F between BOM1 and BOM2 dietary treatments ($P > 0.05$). Throughout the experiment, pigs fed diets supplemented with *E. faecium* and the blend of OAs and MCFAs had higher ($P < 0.05$) ADG and G:F compared with pigs fed CON diet. However, there was no significant

Table 2. Effects of dietary supplementation with *Enterococcus faecium* DSM 7134 and blend of organic acids (OAs) and medium-chain fatty acids (MCFAs) on growth performance in finishing pigs.

	Dietary treatments[a]						Contrast[b]				
Items	CON	BOM1	BOM2	EBOM1	EBOM2	SEM	1	2	3	4	5
Days 1–35											
ADG (g)	798	820	840	860	853	13	0.060	0.002	0.054	0.277	0.697
ADFI (g)	2234	2208	2218	2264	2277	32	0.598	0.366	0.091	0.843	0.785
G:F	0.357	0.371	0.379	0.380	0.375	0.005	0.004	0.002	0.632	0.316	0.316
Days 36–70											
ADG (g)	824	851	871	909	885	15	0.065	0.001	0.030	0.387	0.283
ADFI (g)	2869	2811	2840	2910	2880	33	0.292	0.525	0.049	0.537	0.524
G:F	0.287	0.303	0.306	0.313	0.308	0.005	0.010	0.001	0.113	0.770	0.386
Days 1–70											
ADG (g)	811	836	855	885	869	14	0.055	0.001	0.034	0.319	0.430
ADFI (g)	2551	2509	2529	2587	2578	26	0.323	0.3388	0.026	0.609	0.815
G:F	0.318	0.333	0.338	0.342	0.337	0.004	0.001	<0.001	0.461	0.302	0.174

Note: There were six replicate pens per treatment with four pigs per pen. ADG, average daily gain; ADFI, average daily feed intake; G:F, gain:feed ratio; SEM, standard error of the mean.

[a]Dietary treatments were CON, basal diet; BOM1, basal diet + 500 mg kg^{-1} the blend of OAs and MCFAs; BOM2, basal diet + 1000 mg kg^{-1} the blend of OAs and MCFAs; EBOM1, basal diet + 500 mg kg^{-1} the blend of OAs and MCFAs + 20 mg kg^{-1} *Enterococcus faecium* DSM 7134; and EBOM2, basal diet + 1000 mg kg^{-1} the blend of OAs and MCFAs + 20 mg kg^{-1} *Enterococcus faecium* DSM 7134.

[b]Contrast: 1, CON vs. BOM1 + BOM2; 2, CON vs. EBOM1 + EBOM2; 3, BOM1 + BOM2 vs. EBOM1 + EBOM2; 4, BOM1 vs. BOM2; and 5, EBOM1 vs. EBOM2.

Table 3. Effects of dietary supplementation with *Enterococcus faecium* DSM 7134 and blend of organic acids (OAs) and medium-chain fatty acids (MCFAs) on apparent total tract digestibility in finishing pigs.

	Dietary treatments[a]						Contrast[b]				
Items (%)	CON	BOM1	BOM2	EBOM1	EBOM2	SEM	1	2	3	4	5
Day 35											
Dry matter	74.45	74.66	75.36	77.00	76.64	0.85	0.596	0.030	0.041	0.564	0.767
Nitrogen	73.37	73.62	74.71	76.07	75.86	0.92	0.487	0.029	0.059	0.406	0.873
Day 70											
Dry matter	69.43	69.91	70.84	72.66	72.20	0.92	0.410	0.013	0.034	0.480	0.728
Nitrogen	68.60	68.65	70.11	71.57	70.99	0.94	0.501	0.027	0.054	0.281	0.664

Note: There were six replicate pens per treatment with four pigs per pen. SEM, standard error of the mean.

[a]Dietary treatments were CON, basal diet; BOM1, basal diet + 500 mg kg^{-1} the blend of OAs and MCFAs; BOM2, basal diet + 1000 mg kg^{-1} the blend of OAs and MCFAs; EBOM1, basal diet + 500 mg kg^{-1} the blend of OAs and MCFAs + 20 mg kg^{-1} *Enterococcus faecium* DSM 7134; and EBOM2, basal diet + 1000 mg kg^{-1} the blend of OAs and MCFAs + 20 mg kg^{-1} *Enterococcus faecium* DSM 7134.

[b]Contrast: 1, CON vs. BOM1 + BOM2; 2, CON vs. EBOM1 + EBOM2; 3, BOM1 + BOM2 vs. EBOM1 + EBOM2; 4, BOM1 vs. BOM2; and 5, EBOM1 vs. EBOM2.

difference on growth performance between EBOM1 and EBOM2 dietary treatments ($P > 0.05$). In addition, during days 36 to 70 and days 1 to 70, pigs fed *E. faecium* and the blend of OAs and MCFAs supplemented diets had improved ($P < 0.05$) ADG and ADFI compared with pigs fed the blend of OAs and MCFAs supplemented diets.

Apparent total tract digestibility

Supplementation with the blend of OAs and MCFAs did not affect ATTD of DM or N ($P > 0.05$; Table 3). On days 35 and 70, the ATTD of DM and N were higher ($P < 0.05$) in pigs fed the *E. faecium* and the blend of OAs and MCFAs supplemented diets compared with pigs fed CON diet. However, no significant differences were observed between EBOM1 and EBOM2 dietary treatments for ATTD of DM or N ($P > 0.05$). In addition, on days 35 and 70, pigs fed *E. faecium* and the blend of OAs and MCFAs supplemented diets had higher ATTD of DM compared with pigs fed the blend of OAs and MCFAs supplemented diets ($P < 0.05$).

Table 4. Effects of dietary supplementation with *Enterococcus faecium* DSM 7134 and blend of organic acids (OAs) and medium-chain fatty acids (MCFAs) on blood characteristics in finishing pigs.

	Dietary treatments[a]						Contrast[b]				
Items	CON	BOM1	BOM2	EBOM1	EBOM2	SEM	1	2	3	4	5
Day 35											
BUN (mg dL^{-1})	10.31	10.22	11.18	12.12	11.02	0.45	0.214	0.097	0.558	0.278	0.181
Creatinine (mg dL^{-1})	1.73	1.76	1.78	1.87	1.83	0.10	0.753	0.353	0.446	0.865	0.785
AST (U L^{-1})	57.65	57.11	56.22	52.98	56.15	3.29	0.787	0.423	0.511	0.815	0.486
ALT (U L^{-1})	48.06	46.43	45.21	42.15	42.05	3.55	0.584	0.193	0.337	0.849	0.962
HDL-C (mg dL^{-1})	50.87	50.12	55.20	56.71	55.88	3.94	0.837	0.280	0.281	0.428	0.894
LDL-C (mg dL^{-1})	63.01	62.98	61.22	57.32	57.78	4.31	0.889	0.360	0.341	0.687	0.809
Day 70											
BUN (mg dL^{-1})	12.22	12.05	10.95	10.11	11.41	0.72	0.882	0.197	0.088	0.446	0.797
Creatinine (mg dL^{-1})	2.10	2.06	2.03	1.85	1.93	0.09	0.618	0.076	0.106	0.813	0.519
AST (U L^{-1})	48.08	51.69	37.35	27.15	29.65	8.55	0.737	0.086	0.086	0.249	0.841
ALT (U L^{-1})	40.12	39.39	34.98	32.41	36.23	3.57	0.496	0.178	0.389	0.424	0.539
HDL-C (mg dL^{-1})	53.10	54.39	54.75	60.23	58.11	3.49	0.734	0.173	0.203	0.922	0.769
LDL-C (mg dL^{-1})	78.65	77.12	79.20	75.84	60.34	5.78	0.809	0.147	0.136	0.811	0.075

Note: There were six replicate pens per treatment with four pigs per pen. ALT, alanine aminotransferase; AST, aspartate aminotransferase; BUN, blood urea nitrogen; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; SEM, standard error of the mean.

[a]Dietary treatments were CON, basal diet; BOM1, basal diet + 500 mg kg^{-1} the blend of OAs and MCFAs; BOM2, basal diet + 1000 mg kg^{-1} the blend of OAs and MCFAs; EBOM1, basal diet + 500 mg kg^{-1} the blend of OAs and MCFAs + 20 mg kg^{-1} *Enterococcus faecium* DSM 7134; and EBOM2, basal diet + 1000 mg kg^{-1} the blend of OAs and MCFAs + 20 mg kg^{-1} *Enterococcus faecium* DSM 7134.

[b]Contrast: 1, CON vs. BOM1 + BOM2; 2, CON vs. EBOM1 + EBOM2; 3, BOM1 + BOM2 vs. EBOM1 + EBOM2; 4, BOM1 vs. BOM2; and 5, EBOM1 vs. EBOM2.

Blood parameters and meat quality

No significant differences among any dietary treatments were observed in blood parameters on days 35 and 70 ($P > 0.05$; Table 4). Meat color (L^*, a^*, and b^*), sensory evaluation, cooking loss, pH, LM area, and WHC were not significantly affected by dietary treatments ($P > 0.05$; Table 5). Compared with pigs in CON dietary treatment, drip loss on day 7 was decreased ($P < 0.05$) in pigs fed diets supplemented with *E. faecium* and the blend of OAs and MCFAs. However, no significant differences in drip loss were observed between EBOM1 and EBOM2 dietary treatments ($P > 0.05$).

Discussion

The combination of OAs (calcium formate, calcium lactate, and citric acid) and MCFAs (a mixture of lauric acid, myristic acid, and capric acid) has been previously reported to be able to improve growth performance (increased ADG and ADFI and decreased G:F ratio) compared with zinc oxide in weanling pigs (Kuang et al. 2015). In addition, in our earlier studies using the same blend of OAs and MCFAs as this study, we have demonstrated that supplementation with the blend of OAs and MCFAs improved growth performance in weanling pigs, growing pigs, and finishing pigs (Upadhaya et al. 2014*a*, 2014*b*, 2016; Lei et al. 2017). Similarly, in the present study, throughout the experiment, the supplementation of the blend of OAs and MCFAs increased G:F compared with CON treatment, although no differences on ADG and ADFI were observed. In addition, greater dose (1000 mg kg^{-1}) of the blend of OAs and MCFAs failed to further increase growth performance compared with lower dose (500 mg kg^{-1}). However, Zentek et al. (2013) have indicated that supplementation with OAs (lactic and fumaric acid) and MCFAs (caprylic and capric acid) alone or in combination does not show any beneficial effects on growth performance in weanling pigs. Such inconsistent results might be partly due to differences in the ages of animals used, the types OAs and MCFAs used, and the doses of OAs and MCFAs used.

Various studies have documented the beneficial effects of *E. faecium* DSM 7134 on growth performance in pigs. Lojanica et al. (2010) and Zhang et al. (2014) have found that supplementation with *E. faecium* DSM 7134 improved ADG and feed conversion ratio in weanling pigs. Yan and Kim (2013) have demonstrated that *E. faecium* DSM 7134 supplementation can improve ADG and G:F in growing pigs. In addition, Černauskienė et al. (2011) have reported that *E. faecium* DSM 7134 improved ADG and feed conversion ratio in growing–finishing pigs. In the present study, pigs fed diets supplemented with *E. faecium* DSM 7134 and the blend of OAs and MCFAs showed increased ADG and G:F than pigs fed CON diet. However, no significant difference in growth performance was found between EBOM1 and EBOM2 treatments. In addition, supplementation with the combination of *E. faecium* DSM 7134 and the blend of OAs

Table 5. Effects of dietary supplementation with *Enterococcus faecium* DSM 7134 and blend of organic acids (OAs) and medium-chain fatty acids (MCFAs) on meat quality in finishing pigs.

	Dietary treatments[a]						Contrast[b]				
Items	CON	BOM1	BOM2	EBOM1	EBOM2	SEM	1	2	3	4	5
Meat color											
*L**	48.69	47.79	49.67	49.18	49.09	1.42	0.985	0.804	0.778	0.367	0.966
*a**	14.32	15.26	14.60	14.95	15.19	0.42	0.263	0.175	0.747	0.293	0.696
*b**	3.54	3.61	3.82	3.62	3.88	0.24	0.566	0.497	0.895	0.553	0.472
Sensory evaluation											
Color	3.41	3.34	3.34	3.44	3.38	0.09	0.605	0.991	0.520	1.000	0.641
Firmness	2.36	2.38	2.41	2.59	2.41	0.11	0.810	0.302	0.328	0.847	0.847
Marbling	2.31	2.34	2.38	2.56	2.47	0.09	0.658	0.077	0.095	0.808	0.447
Cooking loss (%)	35.89	37.14	34.80	32.89	34.73	1.48	0.918	0.972	0.933	0.309	0.608
Drip loss (%)											
Day 1	7.00	7.61	7.25	6.26	7.04	0.42	0.421	0.517	0.091	0.564	0.213
Day 3	13.79	12.82	13.78	12.85	12.79	0.43	0.377	0.094	0.291	0.141	0.926
Day 5	19.61	19.40	18.46	19.58	18.98	0.48	0.269	0.585	0.478	0.188	0.394
Day 7	22.99	22.67	22.49	22.05	22.32	0.27	0.261	0.039	0.189	0.651	0.503
pH	5.15	5.14	5.19	5.24	5.21	0.04	0.755	0.124	0.128	0.270	0.526
LM area (cm^2)	59.42	60.13	64.33	65.70	62.53	1.85	0.237	0.060	0.328	0.133	0.249
WHC (%)	41.75	42.64	42.81	44.71	43.86	3.19	0.806	0.528	0.634	0.971	0.854

Note: There were six replicate pens per treatment with four pigs per pen. *a**, redness; *b**, yellowness; *L**, lightness; LM area, *Longissimus* muscle area; WHC, water-holding capacity; SEM, standard error of the mean.

[a]Dietary treatments were CON, basal diet; BOM1, basal diet + 500 mg kg^{-1} the blend of OAs and MCFAs; BOM2, basal diet + 1000 mg kg^{-1} the blend of OAs and MCFAs; EBOM1, basal diet + 500 mg kg^{-1} the blend of OAs and MCFAs + 20 mg kg^{-1} *Enterococcus faecium* DSM 7134; and EBOM2, basal diet + 1000 mg kg^{-1} the blend of OAs and MCFAs + 20 mg kg^{-1} *Enterococcus faecium* DSM 7134.

[b]Contrast: 1, CON vs. BOM1 + BOM2; 2, CON vs. EBOM1 + EBOM2; 3, BOM1 + BOM2 vs. EBOM1 + EBOM2; 4, BOM1 vs. BOM2; and 5, EBOM1 vs. EBOM2.

and MCFAs increased ADG and ADFI during days 36 to 70 and days 1 to 70 compared with supplementation with the blend with OAs and MCFAs alone. These results indicate that supplementation with the combination of *E. faecium* DSM 7134 and blend of OAs and MCFAs in combination exhibited positive synergism effect on growth performance than supplementation with the blend of OAs and MCFAs alone.

Dietary inclusion of a blend of OAs and MCFAs to improve nutrient digestibility has been documented in previous studies (Upadhaya et al. 2014*b*; Kuang et al. 2015). However, in the present study, the ATTD of DM or N was not affected by the blend of OAs and MCFAs compared with CON, which are consistent with our previous findings (Upadhaya et al. 2014*a*, 2016), showing that the blend of OAs and MCFAs had no beneficial effects on ATTD of DM or N. The lack of positive effect on nutrient digestibility may be due to the dosage levels of the blend of OAs and MCFAs, in the present experiment they may have been too low to have an effect on nutrient digestibility.

Chen et al. (2006) observed that the ATTD of DM and N were increased by administration of *E. faecium* SF68 in finishing pigs. Zhang and Kim (2015) have also found that dietary supplementation with *E. faecium* DSM 7134 improved apparent ileal digestibility of crude protein and most of indispensable amino acids in finishing pigs. Another finding in the present study was that the ATTD of DM and N were increased in pigs fed diets supplemented with combination of *E. faecium* DSM 7134 and the blend of OAs and MCFAs, compared with those fed CON diet or diets supplemented with the blend of OAs and MCFAs. In a similar study, with weanling piglets, Mohana Devi and Kim (2014) observed that the ATTD of DM and N were increased by supplementation with a combination of MCFAs (caproic acid, caprylic acid, capric acid, and lauric acid) and *E. faecium* DSM 7134 compared with control diet or diets supplemented with MCFAs or *E. faecium* DSM 7134 alone. Zhang et al. (2016) also demonstrated that a combination of benzoic acid and *E. faecium* SF68 had positive effect on ATTD of N. In the present study, the increased ATTD of DM and N may be a possible reason for the improvement in growth performance in pigs fed diets supplemented with *E. faecium* DSM 7134 and the blend of OAs and MCFAs. Supplementation with OAs may reduce gut pH (de Lange et al. 2010). It has been demonstrated that lower gut pH can improve nutrient digestibility (Canibe and Jensen 2003). It has been previously reported that *E. faecium* DSM 7134 can improve microbial balance (Yan and Kim 2013; Zhang et al. 2014; Zhang and Kim 2015), which may also help to explain the increased nutrient digestibility. In addition, MCFAs have antibacterial effects, which might have contributed to the increased nutrient digestibility in the present

study (Zentek et al. 2012). However, the gut pH and microbial counts were not measured in the present study.

It is known that the increased serum levels of BUN and creatinine indicate a decline in kidney function, whereas higher levels of ALT and AST indicate liver damage (Er and Dik 2014). Serum HDL-C and LDL-C concentrations provide information about lipid metabolism. In the present study, no significant differences in the concentrations of BUN, creatinine, AST, ALT, HDL-C, and LDL-C were observed among treatments, suggesting that supplementation with the blend of OAs and MCFAs with or without *E. faecium* DSM 7134 had no adverse effects on liver and kidney function, or lipid metabolism.

Delivering safe and high-quality meat for human consumption is the primary goal of swine production. Administration of probiotics and OAs could improve meat quality in pigs (Chaucheyras-Durand and Durand 2010; Meng et al. 2010; Ross et al. 2012). Data from the present study indicate that supplementation of the combination of *E. faecium* DSM 7134 and the blend of OAs and MCFAs reduced drip loss. Similarly, Kim et al. (2007) and Suo et al. (2012) observed that supplementation with probiotics reduced drip loss. The reason for such a reduction in drip loss is currently unknown, which requires further studies.

Conclusion

Dietary supplementation with a blend of OAs and MCFAs improved feed efficiency in finishing pigs. Dietary supplementation with the combination of *E. faecium* DSM 7134 and a blend of OAs and MCFAs in finishing pigs enhanced growth performance, improved nutrient digestibility, and reduced drip loss. Moreover, supplementation with the combination of *E. faecium* DSM 7134 and a blend of OAs and MCFAs was more effective in improving growth performance and nutrient digestibility than supplementation with a blend of OAs and MCFAs alone.

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