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Effects of microencapsulated organic acids and essential oils on growth performance and intestinal flora in weanling pigs¤

Efecto de los ácidos orgánicos y aceites esenciales microencapsulados sobre el crecimiento y flora intestinal en cerdos destetos

Efeito dos ácidos orgânicos e óleos essenciais microencapsulados sob a flora intestinal e o crescimento em suínos desmamados

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Summary

Background: dietary supplementation with organic acids and essential oils has positive effects on growth improvement and nutrient digestion. Microencapsulation of nutrients allow for the slow release of core materials in a specific period and/or environment. **Objective:** to investigate the effect of microencapsulated organic acids and essential oils (MOE) on growth performance, nutrient digestibility, blood and fecal characteristics in weanling pigs. **Methods:** one-hundred twenty-five weanling pigs [(Yorkshire × Landrace) x Duroc] with an average body weight (BW) of 6.76 ± 0.11 Kg were used in a 42-d experiment. Pigs were allotted to five dietary treatments according to initial body weight, using five replicates per treatment and five pigs per pen. Dietary treatments were: 1) NC (negative control): basal diet free of antibiotics; 2) PC (positive control), basal diet with tiamulin 39 mg/kg; 3) MOE0.5, basal diet with 0.5 g MOE/kg; 4) MOE1, basal diet with 1 g MOE/kg; and 5) MOE2, basal diet with 2 g MOE/kg. **Results:** final BW was greater in MOE2 and PC treatments compared to NC treatment ($p<0.05$). Increased feed efficiency (G:F) was observed for MOE treatments during 0 to 7 d compared with NC and PC ($p<0.05$). During 7 to 21 d, MOE0.5 and MOE1 supplementation decreased average daily feed intake (ADFI) compared with PC ($p<0.05$). However, there were no differences in average daily gain (ADG) and G:F among treatments ($p>0.05$). During 22 to 42 d, ADG was greater for PC compared with NC ($p<0.05$). The G:F of NC and MOE0.5 was lower than that of PC ($p<0.05$). Overall, ADG and G:F were greater for PC compared to NC ($p<0.05$). On 42 d, DM and N digestibilities in PC and MOE were greater

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($p<0.05$) than in NC. Fecal scores of pigs fed MOE1 were lower ($p<0.05$) than those of pigs fed NC. Fecal pH was decreased in MOE0.5 and MOE1 when compared to NC ($p<0.05$) on day 7. Fecal pH was decreased with MOE compared to NC and PC ($p<0.05$) on d 21. **Conclusion:** MOE supplementation improved growth performance and nutrient digestibility while decreasing fecal scores and pH in weanling pigs.

Keywords: *average daily gain, fecal score, nutrient digestibility, weaned pig.*

Resumen

Antecedentes: la suplementación con ácidos orgánicos y aceites esenciales mejora el crecimiento y digestibilidad de los nutrientes. Los microencapsulados permiten la lenta liberación de materiales en periodos y/o ambientes especiales. **Objetivo:** investigar el efecto de los ácidos orgánicos y aceites esenciales (MOE) microencapsulados sobre el crecimiento, digestibilidad de los nutrientes, y características sanguíneas y de heces en cerdos destetos. **Métodos:** fueron utilizados 125 cerdos destetos [(Yorkshire × Landrace) x Duroc], con un peso promedio (BW) de 6,76 ± 0,11 kg en un experimento con duración de 42 d. Los cerdos fueron asignados a 5 tratamientos dietarios de acuerdo a su peso inicial, 5 réplicas por tratamiento con 5 cerdos por corral. Los tratamientos fueron: 1) control negativo (NC), dieta básica libre de antibióticos; 2) control positivo (PC), dieta básica + tiamulina 39 mg/kg; 3) MOE0.5, dieta básica + 0,5 g MOE/kg; 4) MOE1, dieta básica + 1 g MOE/kg; y 5) MOE2, dieta básica + 2 g MOE/kg. **Resultados:** el peso final fue mayor en MOE2 y PC que en NC ($p<0,05$). Durante los d 0 al 7, los cerdos tuvieron un incremento de la eficiencia alimenticia (G:F) con MOE en comparación con NC y PC ($p<0,05$). Durante los d 7 al 21, disminuyó el consumo promedio de alimento (ADFI) en los cerdos sometidos a MOE0.5 y MOE1 en comparación con PC ($p<0,05$). Sin embargo, no hubo diferencia significativa en la ganancia diaria de peso (ADG) y G:F comparados con PC ($p<0,05$). Durante los d 22 al 42, la ADG fue mayor en PC que en NC ($p<0,05$). En NC y MOE0.5 la G:F disminuyó en comparación con PC ($p<0,05$). La ADG y G:F fue mayor en PC que en NC ($p<0,05$). En el d 42, la digestibilidad de la materia seca y nitrógeno fue mayor ($p<0,05$) en PC y los suplementados con MOE que en NC. La calificación de las heces de cerdos alimentados con MOE1 fue menor ($p<0,05$) que la de NC. El pH fecal disminuyó ($p<0,05$) en MOE0.5 y MOE1 comparado con NC en el d 7. El pH fecal disminuyó en los tratamientos con MOE comparado con NC y PC en el d 21. **Conclusión:** la suplementación con MOE puede mejorar el crecimiento y digestibilidad de los nutrientes, y disminuir la calificación fecal y pH en cerdos destetos.

Palabras clave: *calificación fecal, cerdo desteto, digestibilidad de los nutrientes, ganancia diaria de peso.*

Resumo

Antecedentes: a suplementação com ácidos orgânicos e óleos essenciais melhora o crescimento e a digestibilidade dos nutrientes. A microencapsulação pode permitir a liberação lenta de materiais em um período e/ou ambiente especial. **Objetivo:** pesquisar sobre o efeito dos ácidos orgânicos microencapsulados e óleos essenciais (MOE) no desempenho produtivo, a digestibilidade dos nutrientes, as características sanguíneas e fecais em leitões desmamados. **Métodos:** utilizou-se uma amostra total de 125 leitões desmamados [(York Shire × Landrace) x Duroc] com um peso corporal médio (BW) de 6,76 ± 0,11 kg testados durante 42 d. Os leitões foram distribuídos em cinco tratamentos dietéticos de acordo com seu peso corporal inicial, cinco repetições por tratamento com cinco animais por curral. Os tratamentos foram: 1) NC (controle negativo): dieta basal livre de antibióticos; 2) PC (controle positivo), dieta basal com tiamuline 39 mg/kg; 3) MOE0.5, dieta basal com 0,5 g MOE/kg; 4) MOE1, dieta basal com 1 g MOE/kg; e 5) MOE2, dieta basal com 2 g MOE/kg. **Resultados:** o peso final foi maior em MOE2 e PC do que NC ($p<0,05$). Durante 0-7 d, houve um aumento da eficiência alimentar (G: F) com MOE em comparação com NC e PC ($p<0,05$). Durante o período 7 a 21 d, a suplementação MOE0.5 e MOE1 diminuiu o consumo médio diário de ração (ADFI), em comparação com PC ($p<0,05$). No entanto, não houve diferenças em ganho de peso médio diário (ADG) e G:F entre os tratamentos ($p>0,05$). No período entre os 22 e 42 d, ADG foi maior no tratamento PC que NC ($p<0,05$). Em NC e MOE0.5 a G:F diminui-o em comparação com PC ($p<0,05$). Em geral, a ADG e G:F foram maiores no PC do que NC ($p<0,05$). No dia 42, a digestibilidade da matéria seca e nitrogênio foi maior em PC e MOE que em NC ($p<0,05$). A pontuação fecal de suínos alimentados com MOE1 foi menor que a NC ($p<0,05$). No dia 7 o pH das fezes diminuiu em MOE0.5 e MOE1 em comparação com NC ($p<0,05$). O pH fecal no dia 21 diminuiu com MOE em comparação com NC e PC ($p<0,05$). **Conclusão:** a suplementação com MOE pode melhorar o desempenho de crescimento e digestibilidade de nutrientes, bem como diminuir o escore fecal e pH em leitões desmamados.

Palavras chave: *digestibilidade dos nutrientes, escore fecal, ganho médio diário, leitão desmamado.*

Introduction

The use of antibiotics in livestock feed contributes to the rise of antibiotic-resistant pathogens and antibiotic residue problems in animal products (Kelley *et al.*, 1998), which may pose a potential health hazard to humans (Dipeolu *et al.*, 2005). Therefore, it is essential to find alternatives to the use of antibiotics as growth promoters. Such alternatives are usually organic acids (OAs), probiotics, prebiotics, plant extracts and enzymes (Wang *et al.*, 2009b).

Acidifiers and OAs supplementation improve growth performance (Partanen and Mroz, 1999), nutrient digestibility (Partanen *et al.*, 2007; Walsh *et al.*, 2007; Wang *et al.*, 2009a), gut health (Wang *et al.*, 2009a), blood lymphocyte and white blood cells (WBC) concentration, while decreasing digesta pH in the gastrointestinal tract of pigs (Ravindran and Kornegay, 1993). Limited studies have been conducted on the levels of fecal moisture in OA-treated pigs.

Supplementation of essential oils also improves growth performance (Simonson, 2004; Windisch *et al.*, 2008; Dalkiliç and Güler, 2009) and decreases fecal scores (Hong *et al.*, 2004) because of its antimicrobial effects (Dorman and Deans, 2000).

Microencapsulation allows for the slow release and rumen bypass of nutrients throughout the gastrointestinal tract. Piva *et al.* (2007b) reported that a microencapsulated mixture allowed for slow release of nutrients throughout the gastrointestinal tract. Grilli *et al.* (2008) reported that a microencapsulated mixture (OAs and natural-identical flavors) supplementation improved growth performance of weanling pigs.

Therefore, this study was conducted to investigate the effect of a microencapsulated feed additive containing OAs and essential oils (MOE) on growth performance, nutrient digestibility, blood profile, and fecal traits (score, moisture, and pH) in weanling pigs.

Materials and methods

Location

The experimental protocol was approved by the Animal Care and Use Committee of Dankook University (ACUCDU 1201006) and conducted at the weanling research farm of Dankook University.

Animals and facilities

A total of 125 weanling pigs [(Yorkshire × Landrace) × Duroc] with an average BW of 6.76 ± 0.11 kg (21 d of age) were used in a 42-d experiment. Pigs were randomly allotted to five experimental diets according to their initial BW and sex (with five replicates per treatment and five pigs per pen). All pigs were housed in an environmentally-controlled room, which provided 0.53 m^2 room area per pig. Each pen was equipped with a one-sided stainless steel self-feeder and a nipple drinker that allowed pigs *ad libitum* access to feed and water. Individual BW and feed consumption were recorded on d 1, 7, 21, and 42 to determine average daily gain (ADG), average daily feed intake (ADFI), feed efficiency (G:F) and feed conversion ratio (F:G). Aviplus-S® microencapsulated feed additive containing MOE was used (VetAgro SpA, 42100 Reggio Emilia, Italy). The additive also contained citric (25%), sorbic (16.7%) acids, thymol (1.7%), and vanillin (1.0%).

Dietary treatments

Dietary treatments were: 1) NC (negative control): basal diet free of antibiotics; 2) PC (positive control), basal diet with tiamulin 39 mg/kg; 3) MOE0.5, basal diet with 0.5 g MOE/kg; 4) MOE1, basal diet with 1 g MOE/kg; and 5) MOE2, basal diet with 2 g MOE/kg. The diets were fed during the experiment in three phases: d 0 to 7, 8 to 21, and 22 to 42. All diets (Table 1) were formulated to meet or exceed the NRC (1998) nutrient requirements for weanling pigs.

Sampling and chemical analysis

Apparent total tract digestibility (ATTD) of dry matter (DM) and nitrogen (N) was determined using chromic oxide (0.2%) as an inert indicator (Fenton and Fenton, 1979). Pigs were fed diets mixed with chromic oxide during d 14 to d 21 and d 35 to d 42. Fresh fecal grab samples collected via massaging the rectum of the same 2 pigs per pen on d 21 and d 42, respectively, were mixed and pooled, and a representative sample was stored in a freezer at -20 °C until analysis. Before

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

Item	Phase 1 (d 0 to 7)	Phase 2 (d 8 to 21)	Phase 3 (d 22 to 42)
Ingredient, %			
Corn	-	11.91	28.14
Extruded corn	32.97	28.05	21.91
Soybean meal (48% CP)	23.23	29.80	36.50
Soy oil	4.84	3.70	4.50
Lactose	10.00	8.00	-
Whey	25.00	15.00	5.00
MCP	1.54	1.20	1.40
L-Lys HCl (78%)	0.53	0.54	0.53
DL-Met (50%)	0.22	0.14	0.31
L-Thr (89%)	0.20	0.22	0.21
Vitamin premix[1]	0.10	0.10	0.10
Mineral premix[2]	0.20	0.20	0.20
Limestone	0.97	0.94	0.90
Salt	0.20	0.20	0.30
Calculated nutritional content			
ME, kcal/kg	3,750	3,700	3,650
CP, %	22.50	21.70	20.50
EE, %	7.86	5.99	6.10
CF, %	2.55	2.56	3.04
Lys, %	1.60	1.40	1.35
Ca, %	0.70	0.65	0.62
Total P, %	0.55	0.52	0.50

[1]Provided per kg of complete diet: vitamin A, 11,025 IU; vitamin D_3, 1,103 IU; vitamin E, 44 IU; vitamin K, 4.4 mg; riboflavin, 8.3 mg; niacin, 50 mg; thiamine, 4 mg; d-pantothenic, 29 mg; choline, 166 mg; and vitamin B_{12}, 33 µg.

[2]Provided per kg of complete diet: Cu (as $CuSO_4 \cdot 5H_2O$), 12 mg; Zn (as $ZnSO_4$), 85 mg; Mn (as MnO_2), 8 mg; I (as KI), 0.28 mg; and Se (as $Na_2SeO_3 \cdot 5H_2O$), 0.15 mg.

chemical analysis, the fecal samples were thawed and dried at 70 °C for 72 h, after which they were finely ground to a size that could pass through a 1 mm screen. All feed and fecal samples were analyzed for DM and N following the procedures outlined by the AOAC (2000). Chromium was analyzed via UV absorption spectrophotometry (Shimadzu, UV-1201, Shimadzu, Kyoto, Japan) following the method described by Williams *et al.* (1962). Gross energy was determined by calorimetry using a Parr 6100 oxygen bomb calorimeter (Parr instrument Co., Moline, IL).

Blood profiles of two pigs randomly selected per pen were assessed (based on initial body weight, which was close to the pen average) at the beginning and end of the experiment. Blood samples were collected via puncture of anterior vena cava on d 0 and 42. Blood samples were collected into non-heparinized tubes and vacuum tubes containing K_3EDTA (Becton, Dickinson and Co., Franklin Lakes, NJ) to obtain serum and whole blood, respectively. White blood cells (WBC) and lymphocyte counts in whole blood were determined using an automatic blood analyzer (ADVIA 120, Bayer Corp., Tarrytown, NY, USA). After collection, serum samples were centrifuged (3,000 × g; HANIL SCI MF550, Incheon, Korea) for 15 min at 4 °C. The IgG levels were assessed using an automatic biochemistry analyzer (HITACHI Co 747, Tokyo, Japan).

Fecal scores of all pigs were recorded daily from d 10 through 17 by the same person. The scores were as follow: 1 hard, dry pellet; 2 firm, formed stool; 3 soft, moist stool that retains shape; 4 soft, unformed stool that assumes the shape of the container; 5 watery liquid that can be poured. The average fecal score was used for each pen.

Fecal samples were collected directly from the rectum (via massaging) of 2 pigs in each pen and then pooled and placed on ice and transported to the lab, where analyses were immediately conducted. Fecal samples were collected at days seven, twenty-one, and forty-two of the trial. Fecal moisture was removed using an oven at 80 °C for 72 h. A calibrated, glass-electrode pH meter (Orp Istek 77P, Istek, Korea) was used to measure pH of the fecal samples.

Statistical analysis

Data on growth performance, nutrient digestibility and fecal score were pen-based, whereas data on blood profiles, fecal moisture and fecal pH were based on each individual pig. All data were subjected to GLM procedures of SAS (2010, SAS 9.2 Institute Inc, Cary, North Carolina, USA) as a randomized complete block design. Differences among all treatments were separated by Duncan's multiple range test. Data variability was expressed as standard error (SE). Probability values less than 0.05 were considered significant.

Results

Piglets fed MOE2 and PC had greater ($p<0.05$) final BW (by 0.9 kg and 1.2 kg, respectively) compared with NC (Table 2). During d 0 to 7, ADFI was greater ($p<0.05$) in MOE0.5 and PC compared to NC, while G:F was greater ($p<0.05$) in MOE-supplemented pigs compared with NC and PC. During d 8 to 21, PC-fed animals had greater ADFI than piglets receiving 0.5 or 1 g MOE/kg feed. However, there were no differences in ADG, G:F and feed conversion ratio (F:G) among dietary treatments. During d 22 to 42, ADG was greater ($p<0.05$) in PC when compared with NC-fed piglets. The G:F in NC and MOE0.5 groups resulted lower in this phase when compared with PC-fed pigs. Overall, ADG and G:F were higher ($p<0.05$) in PC than in NC groups, without differences in ADFI. Noticeably, PC did not differ from any of the MOE doses.

Table 2. Effect of MOE supplementation on growth performance in weanling pigs[1].

Items	NC	PC	MOE			SE[2]
			MOE0.5	MOE1	MOE2	
Initial BW	6.76	6.76	6.76	6.76	6.77	0.010
Final BW	25.60^{b}	26.84^{a}	26.01^{ab}	26.21^{ab}	26.48^{a}	0.271
d 0 to 7						
ADG, g	213	220	221	235	231	7
ADFI, g	279^{ab}	284^{a}	257^{b}	277^{ab}	278^{ab}	8
G:F	0.763^{b}	0.775^{b}	0.860^{a}	0.848^{a}	0.831^{a}	0.017
F:G	1.310^{a}	1.291^{a}	1.163^{b}	1.179^{b}	1.203^{b}	0.026
d8 to 21						
ADG, g	405	426	411	401	427	10
ADFI, g	523^{ab}	542^{a}	504^{b}	498^{b}	523^{ab}	10
G:F	0.774	0.786	0.815	0.805	0.816	0.018
F:G	1.291	1.272	1.226	1.242	1.225	0.029
d 22 to 42						
ADG, g	556^{b}	599^{a}	569^{ab}	580^{ab}	578^{ab}	13
ADFI, g	896	891	901	908	898	16
G:F	0.621^{b}	0.672^{a}	0.631^{b}	0.639^{ab}	0.645^{ab}	0.014
F:G	1.612^{a}	1.487^{b}	1.583^{ab}	1.566^{ab}	1.555^{ab}	0.034
Overall						
ADG, g	449^{b}	478^{a}	458^{ab}	463^{ab}	470^{ab}	6
ADFI, g	668	674	680	666	670	9
G:F	0.672^{b}	0.709^{a}	0.674^{ab}	0.696^{ab}	0.701^{ab}	0.010
F:G	1.488^{a}	1.410^{b}	1.485^{ab}	1.438^{ab}	1.426^{ab}	0.020

[1]Abbreviation: NC, free of antibiotics; PC, antibiotics (39 mg/kg tiamulin); MOE0.5, NC + 0.05% MOE (microencapsulated organic acid and essential oils); MOE1, NC + 0.10% MOE; MOE2, NC + 0.20% MOE.

[2]Standard error.

[a,b]Means in the same row with different superscripts differ ($p< 0.05$).

Table 3. Effect of MOE supplementation on digestibility in weanling pigs[1].

	NC	PC	MOE			SE[2]
			MOE0.5	MOE1	MOE2	
d 21						
DM	81.76	82.02	82.01	82.32	82.23	0.202
N	82.02	82.37	81.81	82.25	82.24	0.347
Gross energy	82.57	82.89	82.76	83.26	82.93	0.243
d 42						
DM	80.71[b]	81.07[a]	81.09[a]	80.96[a]	81.05[a]	0.052
N	80.23[b]	81.17[a]	81.40[a]	81.55[a]	81.63[a]	0.231
Gross energy	80.93	81.23	81.39	81.33	81.07	0.139

[1]Abbreviation: NC, free of antibiotics; PC, antibiotics (39 mg/kg tiamulin); MOE0.5, NC + 0.05% MOE (microencapsulated organic acids and essential oils); MOE1, NC + 0.10% MOE; MOE2, NC + 0.20% MOE.

[2]Standard error.

[a,b]Means in the same row with different superscripts differ ($p<0.05$).

Table 4. Effect of MOE supplementation on blood profile of weanling pigs[1].

Item	NC	PC	MOE			SE[2]
			MOE0.5	MOE1	MOE2	
Initial d1						
IgG, mg/dL	317.8	337.8	346.9	323.2	327.7	37.701
WBC, 10^3/µl	12.58	12.74	12.67	12.68	12.61	2.146
Lymphocyte, %	58.57	58.84	58.28	59.07	58.77	3.681
Final d42						
IgG, mg/dL	329.2	315.5	336.7	340.1	325.6	31.700
WBC, 10^3/µl	13.40	13.17	14.01	13.77	13.99	3.373
Lymphocyte, %	57.70	57.32	55.29	54.53	56.93	5.413

[1]Abbreviation: NC, free of antibiotics; PC, antibiotics (39 mg/kg tiamulin); MOE0.5, NC + 0.05% MOE (microencapsulated organic acids and essential oils); MOE1, NC + 0.10% MOE; MOE2, NC + 0.20% MOE; WBC, white blood cells.

[2]Standard error.

No difference was observed in ATTD of DM, N, and energy among dietary treatments on d 21 (Table 3). On d 42, DM and N digestibility in PC and MOE treatments was higher ($p<0.05$) than that in NC treatment, but energy digestibility was not affected by dietary treatments.

No differences were observed on IgG, WBC concentration, and lymphocyte counts among dietary treatments on d 1 and 42 (Table 4).

Fecal score was lower ($p<0.05$) in MOE1 compared with NC (Table 5). Fecal moisture was unaffected by dietary treatments (Table 5). Fecal pH was decreased ($p<0.05$) in MOE0.5 and MOE1 compared with NC and MOE2 groups on d 7. On d 21, fecal pH was decreased ($p<0.05$) with MOE supplementation compared with NC and PC treatments.

Table 5. Effect of MOE supplementation on fecal score, moisture and pH in weanling pigs[1].

Item	NC	PC	MOE			SE[2]
			MOE0.5	MOE1	MOE2	
Fecal score[3]	3.29[a]	3.20[ab]	3.19[ab]	3.08[b]	3.20[ab]	0.05
Fecal moisture, %						
d 7	71.61	71.89	72.26	73.60	72.53	1.041
d 21	72.87	73.15	73.24	71.04	73.30	1.712
d 42	68.34	74.23	71.90	73.90	75.83	2.783
Fecal pH						
d 7	6.28[a]	6.20[bc]	6.13[c]	6.18[c]	6.26[ab]	0.021
d 21	6.20[a]	6.22[a]	5.92[b]	5.94[b]	5.87[b]	0.044
d 42	6.03	6.07	6.00	6.04	5.97	0.041

[1]Abbreviation: NC, free of antibiotics; PC, antibiotics (tiamulin 39 mg/kg); MOE0.5, NC + 0.05% MOE (microencapsulated organic acids and essential oils); MOE1, NC + 0.10% MOE; MOE2, NC + 0.20% MOE.

[2]Standard error.

[3]Fecal scores were determined at 08:00 and 20:00 h using the following fecal scoring system: 1 hard, dry pellet; 2 firm, formed stool; 3 soft, moist stool that retains shape; 4 soft, unformed stool that assumes shape of container; 5 watery liquid that can be poured.

[a,b,c]Means in the same row with different superscripts differ ($p < 0.05$).

Discussion

MOE could be used as an alternative to antibiotics in weanling pigs to improve growth performance due to its antimicrobial effects (Silvia and Asensio, 2002; Cho *et al.*, 2006). Grilli *et al.* (2008) also reported that supplementation of 0.3% microencapsulated blend (OAs and natural identical flavors) improved ADG and feed efficiency compared with the control group during d 1 to d 14 after weaning. Also, Piva *et al.* (2007b) reported that final BW were 4.8 and 6.2% greater for weanling pigs fed a microencapsulated blend of tributyrin and lactitol than a diet based on vegetable protein without growth-promoters after 21 and 35 d, respectively, and overall ADG, ADFI, and G:F were 11.1, 2.2, and 8.0% greater, respectively. Piva *et al.* (2007a) demonstrated that piglets receiving microencapsulated acidifier had similar body weight and animals receiving 0.1% microencapsulated blend (OAs and natural identical flavors) were numerically heavier than animals fed 11 kg/ton of formic (64%) and lactic (36%) acids at d 21 and 49. The present study confirms previous reports indicating a potential synergic effect of MOE when added to weanling pig diets. Moreover, the increased digestibility of DM and N may be the most important reason for the improved growth performance.

Organic acids influence mucosal morphology, stimulate pancreatic secretions, and improve protein digestibility by lowering gastric pH, which consequently increases pepsin activity as well as absorption and retention of dietary nutrients (Partanen and Mroz, 1999; Partanen *et al.*, 2007). Organic acids supplementation reduces bacterial protein synthesis and dietary buffering capacity (Partanen *et al.*, 2001). Mroz *et al.* (2000) suggested that OAs have a beneficial effect on apparent ileal and total tract digestibilities, as well as calcium digestibility in growing pigs. This may be because the addition of OAs to the diet lowered diet acidity. Lowering the dietary pH may increase solubility of minerals, thereby increasing calcium absorption. In agreement with this study, Partanen *et al.* (2007) demonstrated that dietary OAs improved apparent ileal digestibility in pigs.

Windisch *et al.* (2008) suggested that phytogenic compounds, mainly essential oils, could enhance digestive enzyme activity and nutrient absorption, which could improve the biological value of low-density diets. Cho *et al.* (2006) reported that N digestibility was increased by essential oil supplementation in weanling pigs. Yan *et al.* (2010) showed that essential oil supplementation had a positive effect on N digestibility. Dietary MOE function via alterations of gut microflora and enhanced nutrient sparing. Piva *et al.* (2007b) reported that lipid microencapsulation allows a slow-release of OAs and natural identical flavors along the swine intestine.

Fecal consistency is related to fluid absorption and secretion, which may be affected by some pathogens. Burt (2004) reported that essential oils, which have known antimicrobial function, could inhibit pathogens shedding in the intestine, leading to a decreased fecal score. Consistent with this study, Hong *et al.* (2004) reported that fecal score decreased after feeding weaned piglets a plant extract (citrus fruit and chestnut tree extract mixture).

Microbial populations of the digestive tract vary with factors such as pH, transit time, and nutrient density. The addition of OAs to pigs diet decreases gut pH and improves gastrointestinal (GI) tract function by decreasing *E. coli* proliferation. Organic acids are able to enter the microbial cell, where acids release the proton in the more alkaline environment, resulting in decreased intracellular pH. The GI tract of weanling pigs is not fully developed and has limited capacity to maintain its optimal pH (Ravindran and Kornegay, 1993). Supplementation with organic acids reduces pH of diet and digesta in pigs, especially in weanling pigs (Kirchgessner and Roth, 1982). In agreement with these reports, pigs fed MOE had lower fecal pH on d 7 and 21 in the present study.

In conclusion, our results suggest that MOE with lipid microencapsulation could improve growth performance compared with pigs fed the antibiotic, with 2 g/kg resulting in the highest values. In terms of nutrient digestibility, MOE significantly increased nutrient digestibility compared with the non-antibiotic treatment. Furthermore, inclusion of MOE significantly decreased fecal pH compared with the other treatment at d 21, indicating that lipid microencapsulation effectively affected the intestinal environment in this study. Collectively, our study suggested that MOE could be used as an alternative to antibiotics for weaning pigs.

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Conflicts of interest

The authors declare they have no conflicts of interest with regard to the work presented in this report.

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