Effects of microencapsulated complex of organic acids and essential oils on growth performance, nutrient retention, blood profiles, fecal microflora and lean meat percentage in weaning to finishing pigs

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Effects of microencapsulated complex of organic acids and essential oils on growth performance, nutrient retention, blood profiles, fecal microflora and lean meat percentage in weaning to finishing pigs.

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ABSTRACT

A total of 90 pigs (6.47 ± 0.27 kg; 21 d of age) were used in this 22-wk feeding trial to evaluate the effect of microencapsulated complex of organic acids and essential oils (MOE) on growth performance, nutrient retention, blood profile, fecal microflora and lean meat percentage in pigs. Pigs were randomly distributed to one of three treatment groups (6 replicate pens / treatment, 5 pigs / pen). Dietary treatments were: CON, basal diet; MOE 1, basal + 0.1% MOE, MOE2, basal diet + 0.2% MOE.

The ADG, ADFI and G/F ratio were significantly different among treatments ($P < 0.05$). The ATTD of DM was linearly increased ($P < 0.05$) by MOE2. RBC and IgG were significantly different in pigs fed MOE ($P < 0.05$). The *Lactobacillus* concentration linearly increased ($P < 0.05$) in MOE2 treatments compared with other treatments. The meat color (a^*) and drip loss decreased linearly ($P < 0.05$) with increasing level of MOE. In conclusion, MOE supplementation could improve growth performance, nutrient retention, blood profile, fecal microflora and carcass trait in weaning to finishing pigs.

Key words: microencapsulation, organic acids, essential oils; growth performance; nutrient retention; pigs

Abbreviations: OA, organic acid; EO, essential oil; MOE, microencapsulated complex of organic acids and essential oils; BW, body weight; CON, control diet; ADG, average daily gain; ADFI, average daily feed intake; G:F, feed efficiency; ATTD, apparent total tract digestibility; DM, dry matter; N, nitrogen; UV, ultraviolet; IgG, immunoglobulin G; WBC, white blood cell; RBC, red blood cell; L*, lightness; a^* , redness; b^* , yellowness; WHC, water holding capacity; LMA, longissimus muscle area; GLM, general linear model;

INTRODUCTION

The first ban on the farm use of antibiotic growth promoters was enacted in 1986 in Sweden because antibiotics in livestock feed increase numbers of antibiotic-resistant pathogens and antibiotic residue problems in animal products (Kelley et al., 1998). It is well accepted that organic acid (OA) can reduce the pH in the gastrointestinal tract and moderate the microorganism balance (Canibe et al., 2005). Feeding OA to farm animals improved growth performance and nutrient retention (Wang et al., 2009). Similar to organic acid, pure botanicals, which are also referred as volatile or ethereal oils acquired from natural plant materials, can also affect animal growth performance (Simonson, 2004) and nutrient retention (Windish et al., 2008) by enhancing digestive enzyme activity and nutrient absorption (Burt, 2004).

Essential oils (EO) extracted from edible plants such as thymol and vanillin have broad spectrum of antimicrobial activity due to high content of phenolic derivatives (Falcone et al., 2005). Organic acid and EO have an antimicrobial action in common and are emerging as substitute for antibiotics (Canibe et al., 2005; Cho et al., 2006). Microencapsulation technology can be used to solve this problem because they allow for the slow release and passes along the intestine (Piva et al., 1997). Many studies have shown that microencapsulated blend (OA and EO) improved growth performance and odor reduction of pigs (Grilli et al., 2010; Cho et al., 2006) and improved broilers meat quality (Goksoy et al., 2010).

Therefore, we conducted this study to evaluate the effect of microencapsulated complex of organic acids and essential oils (MOE) supplementation on growth performance, nutrient retention, blood profiles, and fecal microflora in weaning to finishing pigs.

MATERIALS AND METHODS

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The experimental protocols describing the management and care of animals were reviewed and approved by the Animal Care and Use Committee of Chungbuk National University.

Animals and Facilities

A total of 90 weaned pigs [(Yorkshire × Landrace) × Duroc] with an average body weight (BW) of 6.47 ± 0.27 kg were used in a 22-wk experiment. Pigs were allotted to one of three dietary treatment in a completely randomized block design based on initial BW. There were five pigs treatment in a pen and six replicate pen per treatment. All pigs were housed in an environmentally-controlled room, which provided 0.26m^2 for each growing pig and 0.53m^2 for each finishing pig. Each pen was equipped with a one-sided, stainless steel self-feeder and a nipple drinker. Feed and water were available ad libitum. Individual pig BW and feed disappearance were recorded at the end of wk 1, 3, 6, 12, 17 and 22 to determine average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (G/F) ratio.

Dietary Treatments

Dietary treatments were: Control (CON), basal diet; MOE1, basal + 0.1% (weanling phase) & 0.025% (growing-finishing phase) MOE; MOE2, basal diet + 0.2% (weanling phase) & 0.05% (growing-finishing phase) MOE. The diets were fed during the experiment in 3 phases: d 0 to 42, 43 to 84, and 85 to 154. The MOE is a microencapsulated feed additive containing organic acids and pure botanicals from VetAgroSpA (Aviplus[®]-S, 42100 Reggio Emilia, Italy), contained citric (25%), sorbic (16.7%) acids, thymol (1.7%) and vanillin (1.0%).

All diets, in pelleted form, were formulated to meet or exceed the nutrient requirements (NRC, 2012) for pigs. Treatment additives were included in the diet by replacing the same

amount of corn, and each treatment was made isolysinic and isocaloric by manipulation of soybean meal and fat source.

Sampling and Measurements

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 from d 15 to 21, 36 to 42, 78 to 84 and 147 to 154. Fresh fecal grab samples collected from 8 pigs per treatment (d 21, 42 and 84) were mixed and pooled, and a representative sample was stored in a freezer at -20°C until analyzed. Before 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, then, 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).

For the serum profile, 5 pigs from each treatment were randomly selected and blood samples were collected via anterior vena cava puncture at the end of wk 6, 12, and 22. At the time of collection, blood samples were collected into both non-heparinized tubes and vacuum tubes containing K₃EDTA (Becton, Dickinson and Co., Franklin Lakes, NJ) to obtain serum and whole blood, respectively. After collection, serum samples were centrifuged ($3,000 \times g$) for 15mins at 4°C. The white blood cells (WBC), red blood cells (RBC), lymphocyte counts, as well as the immunoglobulin G (IgG) concentration in the whole blood were determined using an automatic blood analyzer (ADVIA 120, Bayer, NY).

Procedures of Microbial Shedding

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Fecal samples were collected directly via massaging the rectum of 4 pigs in each treatment and then pooled and placed on ice for transportation to the lab. 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) 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) 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.

Carcass traits

Twenty pigs were randomly selected from each treatment at the end of experiment period and backfat thickness and LMP measurements were performed using a real time ultrasound instrument (Piglog 105, SFK Technology, Herlev, Denmark).

Meat quality

Five pigs of each treatment were slaughtered at the end of 22th wk. After chilling at 2°C for 24 h, one 2.54-cm-thick longissimus muscle sample was abstained at the 10th rib (right side of the carcass). The reflectance spectrometry measurements of lightness (L^*), redness (a^*) and yellowness (b^*) values were determined by MinoltaCR410 chroma meter (Konica Minolta Sensing, Inc., Osaka, Japan). Sensory evaluation (color, marbling and firmness scores) was evaluated according to National Pork Producers Council standards (NPPC 1991). Drip loss was determined as a percentage of the original weight using 2 g of meat sample

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according to the method of Honikel (1998). The weight of each sample was taken before and after cooking to determine cooking loss, which was defined as the cooked weight divided by uncooked weight multiplied by 100. Duplicate pH values of each sample were measured via a glass-electrode pH meter (WTW pH 340-A, WTH Measurement Systems Inc. Ft. Myers, FL). Water holding capacity (WHC) was measured followed the guide of Kauffman et al. (1986). Longissimus muscle area (LMA) was measured by tracing the longissimus muscle surface at the 10th rib, which also used the above mentioned digitizing area-line sensor.

Statistical Analysis

All data were subjected to the statistical analysis as a randomized complete block design using the general linear model (GLM) procedures of SAS (SAS Inst. Inc., Cary, NC), and the pen was used as the experimental unit. The initial BW was used as a covariate for ADFI and ADG, and initial values was used as a covariate for blood profile. Before carrying out statistical analysis of the microbial counts, logarithmic conversion of the data was performed. Because of the design, linear and quadratic effects of treatment were assessed. Different among treatment means were determined using the Turkey's multiple range test with a $P < 0.05$ indicating a significance.

RESULTS

Growth performance

The pigs' body weight increased linearly ($P = 0.003, 0.002, 0.001$) with increased MOE at the end of wks 6, 17, and 22 (Table 4). Moreover, pigs fed with the MOE2 diet had higher ($P < 0.05$) body weight than did the pigs fed with the CON (control) diet at the end of wks 6, 17, and 22. From wk 0 to wk 6, pigs fed with MOE2 had higher ($P < 0.05$; linear $P = 0.001$) ADFI than did those fed with the CON or MOE1 diets. From wk 3 to wk 6, ADG increased linearly

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($P = 0.040$) with increased MOE. From wk 0 to wk 6, pigs fed the MOE2 diet had higher ADG than did pigs fed the CON diet ($P < 0.05$; linear $P = 0.006$).

From wk 12 to wk 17, pigs fed the AV2 diet had higher ADG and G/F than did pigs fed the CON diet ($P < 0.05$; linear $P = 0.040$, $P = 0.024$). From wk 17 to wk 22, pigs fed the CON diet had higher ADFI than did pigs fed the MOE diet ($P < 0.05$; linear $P = 0.017$; quadratic $P = 0.019$). From wk 12 to wk 22, pigs fed the MOE2 diet had higher ADG, ADFI, and G/F ratio than did pigs fed the CON diet ($P < 0.05$; linear $P = 0.019$, 0.017 , 0.005).

Overall (wks 0 to 22), pigs fed the MOE2 diet had the highest ADG and G/F ratios of all treatments ($P < 0.05$; linear $P = 0.001$, 0.001).

Nutrient retention

At wk 3, the ATTD of DM increased in pigs fed with MOE2 ($P < 0.05$) compared with pigs fed CON and MOE1 (Table 5). Pigs fed the MOE2 diet had higher ATTD of DM than did pigs fed the CON and MOE1 diets ($P < 0.05$; linear $P = 0.011$). At wk 6, the ATTD of DM increased ($P < 0.05$; linear $P = 0.007$) in the MOE2 treatment.

Blood profiles

At wk 6, pigs fed the MOE1 diet had higher RBC concentrations than did pigs fed the MOE2 diet ($P < 0.05$; quadratic $P = 0.020$) (Table 6). IgG concentration was higher ($P < 0.05$; linear $P = 0.027$) in pigs fed the MOE2 diet than in those fed the CON diet. At wk 22, pigs fed the MOE1 diet had higher RBC concentrations than did pigs fed the MOE2 diet ($P < 0.05$; quadratic $P = 0.030$).

Fecal microflora

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At wk 6, fecal *Lactobacillus* concentration increased ($P < 0.05$; linear $P = 0.044$; quadratic $P = 0.045$) in MOE2 (Table 7).

Carcass traits

We observed no significant differences ($P > 0.05$) in backfat thickness or LMP among treatments (Table 8).

Meat quality

The meat color (a^*) drip loss on d 7 decreased ($P < 0.05$; linear $P = 0.028$, quadratic $P = 0.026$) in MOE1, MOE2 treatments compared with CON treatment (Table 9). We also observed no significant differences ($P > 0.05$) in meat color, cooking loss, sensory evaluation, pH, water holding capacity, or *longissimus* muscle area among treatments.

DISCUSSION

In this study, adding MOE to pig feed improved growth performance during the overall period and improved nutrient retention and fecal microflora during the weanling period. Constituent OA promotes nutrient retention by lowering the pH of the gastrointestinal tract (Busser et al., 2011); in particular, it helps to digest crude fiber and non-starch polysaccharide and carbohydrate with essential oil (Gerritsen et al., 2010). Lim et al. (2015) reported that most OA was absorbed in intestinal epithelial cells by passive diffusion. Moreover, OA can be used in metabolic pathways for TCA cycle and ATP generation (Lin et al., 2017). As the MOE essential oil, thymol is extracted from plants and improves feed efficiency and changes in gut luminal metabolites (Grilli et al., 2010). Microencapsulation can deliver nutrients throughout the gastrointestinal tract and protect amino acids and proteins (Piva et al., 1997). For this reason, microencapsulation could increase the effects of OA and EO (Cho et al., 2014).

In the present study, treatment linearly increases ADFI and ADG during the weanling to growing and growing to finishing periods, and similar results were found in other studies; OA and EO improved ADG and G:F at end of week 6 (Xu et al., 2018; Huang et al., 2010; Hong et al., 2004; Cho et al., 2006). Upadhaya et al. (2014) demonstrated that OA reduced pathogenic microbes and allowed the host to use energy required for microbial metabolism. In another study, adding vanillin, an EO, improved feed intake and ADG (Gallage et al., 2014). In our previous study, we conducted similar experiments with only finishing pigs (Cho et al., 2014), and the microencapsulated mixture significantly improved growth performance.

In this study, the ATTD of DM increased linearly ($P=0.011$, 0.007) at week 3 and week 6, but there were no significant differences during other periods; there were also no significant differences in nitrogen and energy retention. However, many other studies showed increased nitrogen retention in pigs fed OA and EO (Cho et al., 2006; Kwak et al., 2017; Y. T. Xu et al.,

2018) by lowering gastrointestinal tract pH, which increased the activity of digestive enzymes such as pepsin and trypsin (Burt, 2004; Long et al., 2018). In our previous study (Cho et al., 2014), energy retention also increased linearly ($P < 0.05$), but we could not find any significant difference in this study.

In blood profiles, IgG concentration increased linearly ($P = 0.027$) at week 6. OA and EO function to enhance immune system and antibacterial activity (Wenk, 2003). In the present study, red blood cell (RBC) concentrations showed quadratic effects ($P = 0.020$, $P = 0.030$) with MOE density at weeks 6 and 22. However, Hong et al. (2004) and Lien et al. (2006) reported that essential oil and organic acid supplementation did not affect RBC concentration. Therefore, we need additional studies about the effects of OA and EO on pigs' RBC concentrations.

In other studies of pigs fed with OA and essential oils, authors also reported that OA prevents growing gut microbial pathogens without damaging beneficial bacteria such as *Lactobacillus* (Øverland et al., 2008; Schöner, 2001; Long et al., 2018). In our study, however, the effect of MOE on fecal microflora such as *E. coli* was not significantly different. Fecal *Lactobacillus* increased linearly ($P = 0.044$) at 6 weeks, and similarly, in a different study, OA and essential oil improved *Lactobacillus* in weanling piglets (Y. K. Xu et al., 2017).

Our study showed no effects of OA or EO on the pigs' carcass traits, similar to our previous study findings (Cho et al., 2014). However, we did find significant differences in meat color and drip loss in terms of meat quality, whereas in our previous study, there were no effects on meat quality (Cho et al., 2014). In this study, the redness of the meat (a^*) decreased linearly in the treatment groups, and low redness has the disadvantage that consumers prefer darker meat. However, this finding was different from that in our previous study (Cho et al., 2014), and thus it seems that more research is required. Sorbic and para-aminobenzoic acids used as antimicrobial agents in meat packing reduce drip loss (Cutter, 1999), but we also found no

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significant difference in our previous study (Cho et al., 2014), so again, more research is needed.

CONCLUSION

Supplementing the diets with 0.2% MOE could increase BW, ADFI, ADG and G/F linearly; also MOE had a positive effect on ATTD of DM. It was observed that supplementing the diets with 0.2% MOE increased the levels of RBC and IgG and also they had a positive influence on increasing fecal *lactobacillus* counts. Moreover, MOE had a significant effect on reducing meat color (a^*) and drip loss.

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Table 1. Compositions of the basal weanling diets (as-fed basis)

Items	Day1 to 7	Day8 to 21	Day 22 to 42
Ingredient, %			
Extruded corn	29.18	44.49	61.97
Soybean meal, 48% CP ^a	6.94	16.20	25.30
Fermented soybean meal, 45%CP	10.00	5.00	2.50
Fish meal, 66% CP	5.00	3.50	-
Soy oil	3.65	2.55	1.05
Lactose	15.30	8.30	-
Whey	15.00	10.00	5.00
Monocalcium phosphate	1.45	-	-
Dicalcium phosphate	-	1.50	1.50
Sugar	5.00	3.00	-
Plasma powder	6.00	3.00	-
L-Lysine-HCl, 78%	0.29	0.39	0.46
DL-Methionine, 50%	0.32	0.30	0.24
L-Threonine, 89%	0.13	0.19	0.20
Choline chloride, 25%	0.20	0.10	0.10
Vitamin premix ^b	0.10	0.10	0.10
Trace mineral premix ^c	0.20	0.20	0.20
Limestone	1.24	0.98	1.13
Salt	-	0.20	0.25
Total	100.00	100.00	100.00

Analyzed composition, %

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ME, kcal/kg	3,591	3,534	3,409
CP	21.12	19.87	19.07
Lys	1.65	1.53	1.32
Met	0.61	0.60	0.55
Ca	0.97	0.91	0.87
P	0.82	0.73	0.67

^aCP, crude protein.

^bProvided per kg of complete diet: vitamin A, 11,025 IU; vitamin D₃, 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 B₁₂, 33 µg.

^cProvided per kg of complete diet: Cu (as CuSO₄•5H₂O), 12 mg; Zn (as ZnSO₄), 85 mg; Mn (as MnO₂), 8 mg; I (as KI), 0.28 mg; and Se (as Na₂SeO₃•5H₂O), 0.15 mg.

Table 2. Composition of the basal growing diets (as-fed basis)

Items	Content
Ingredients, g/kg	
Corn	55.38
Soybean meal	33.43
Molasses	2.50
Animal fat	5.33
Difluorinated phosphate	1.93
Limestone	0.78
L-lysine HCl	0.17
Trace mineral premix ^a	0.10
Vitamin premix ^b	0.12
Salt	0.20
DL-methionine	0.03
Choline chloride	0.03
Analyzed composition	
ME, Kcal/kg	3,372
CP, %	19.65
Ca, %	0.87
P, %	0.76

^aProvided per kg of complete diet: 12.5 mg Mn, 179 mg Zn, 140 mg Cu, 0.5 mg I and 0.4 mg Se.

^bProvided per kg of complete diet: 20,000 IU of vitamin A; 4,000 IU of vitamin D3; 80 IU of vitamin E; 16 mg of vitamin K3; 4 mg of thiamine, 20 mg of riboflavin; 6 mg of

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pyridoxine; 0.08 mg of vitamin B12; 120 mg of niacin; 50 mg of Ca-pantothenate; 2 mg of folic acid and 0.08 mg of biotin.

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Table 3. Composition of basal finishing diets (as-fed basis)

Items	Content
Ingredients, %	
Ground corn	59.30
Soybean meal (CP 47.5%)	31.68
Tallow	2.79
Molasses	3.00
Limestone	0.36
Phosphorus	1.84
Salt	0.15
L-Lys·HCl(78%)	0.27
DL-Met(50%)	0.10
L-Thr(89%)	0.07
Choline chloride (25%)	0.11
Vitamin premix ^a	0.13
Trace mineral premix ^b	0.20
Analyzed composition	
ME, kcal/kg	3,311
CP, %	17.41
Ca	0.78
Available P	0.61
Lys	1.09

^aProvided per kg of complete diet: vitamin A, 4000 IU; vitamin D₃, 800 IU; vitamin E, 171 IU; vitamin K, 2 mg; riboflavin, 4 mg; niacin, 20 mg; thiamine, 4 mg; d-

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pantothenic, 11 mg; choline, 166 mg; biotin, 0.08 mg; and vitamin B₁₂, 16 µg.

^bProvided per kg of complete diet: Cu (as CuSO₄·5H₂O), 15 mg; Fe (as FeSO₄·7H₂O), 80 mg; Zn (as ZnSO₄), 56 mg; Mn (MnO₂), 74 mg; I (as KI), 0.3 mg; Co (as CoSO₄·5H₂O), 0.5 mg; and Se (as Na₂SeO₃·5H₂O), 0.4 mg.

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Table 4. The effect of microencapsulated complex of organic acids and essential oilssupplementation on growth performance in weaning to finishing pigs.^a

Item	CON	MOE1	MOE2	SEM ^b	Linear ^c	Quadratic ^c
Body						
weight,						
kg						
Initial	6.47	6.47	6.48	0.05	0.924	0.951
1wks	7.82	7.88	8	0.07	0.095	0.713
3wks	13.94	14.21	14.4	0.16	0.056	0.821
6wks	25.97 ^b	26.41 ^{ab}	27.06 ^a	0.24	0.003	0.780
12wks	54.66	55.3	56.96	0.89	0.079	0.642
17wks	83.36 ^b	84.56 ^b	87.73 ^a	0.95	0.002	0.408
22wks	109.29 ^b	111.65 ^b	114.89 ^a	1.10	0.001	0.734
Week 0-1						
ADG, g	193	201	217	8.66	0.061	0.703
ADFI, g	234 ^c	252 ^b	268 ^a	2.57	0.001	0.785
G/F	0.825	0.798	0.81	0.034	0.710	0.679
Week 1-3						
ADG, g	437	452	457	9.82	0.172	0.651
ADFI, g	637 ^b	631 ^b	648 ^a	3.31	0.010	0.006
G/F	0.686	0.716	0.705	0.016	0.453	0.269
Week 3-6						
ADG, g	573 ^b	581 ^{ab}	603 ^a	9.34	0.040	0.604
ADFI, g	961 ^b	969 ^b	993 ^a	6.83	0.002	0.369
G/F	0.596	0.6	0.607	0.009	0.504	0.932
Week 0-6						

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ADG, g	464 ^b	475 ^{ab}	490 ^a	5.98	0.006	0.803
ADFI, g	732 ^b	737 ^b	757 ^a	3.92	0.001	0.123
G/F	0.634	0.645	0.647	0.008	0.341	0.678
Week 6-12						
ADG, g	683	688	712	19.96	0.302	0.677
ADFI, g	1467	1469	1460	3.69	0.267	0.220
G/F	0.466	0.468	0.488	0.013	0.224	0.571
Week 12-17						
ADG, g	820 ^b	836 ^{ab}	879 ^a	19.65	0.040	0.592
ADFI, g	1939	1938	1904	17.07	0.220	0.490
G/F	0.423 ^b	0.431 ^{ab}	0.462 ^a	0.012	0.024	0.500
Week 17-22						
ADG, g	741	774	776	21.71	0.248	0.592
ADFI, g	2619 ^a	2579 ^b	2589 ^b	8.49	0.017	0.019
G/F	0.283	0.3	0.3	0.008	0.153	0.420
Week 12-22						
ADG, g	781 ^b	805 ^{ab}	828 ^a	13.85	0.019	0.967
ADFI, g	2279 ^a	2259 ^{ab}	2247 ^b	8.57	0.017	0.625
G/F	0.343 ^b	0.356 ^{ab}	0.368 ^a	0.006	0.005	0.905
Week 0-22						
ADG, g	668 ^b	683 ^b	704 ^a	7.30	0.001	0.740
ADFI, g	1635	1628	1626	4.50	0.210	0.605
G/F	0.409 ^b	0.42 ^b	0.433 ^a	0.004	0.001	0.819

Note: Means in the same row with different superscripts differ ($P < 0.05$).

^aAbbreviation: CON, basal diet; MOE1, basal + 0.1%(weanling phase) & 0.025% (growing

finishing phase) microencapsulated complex of organic acids and essential oils; MOE2, basal +

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0.2%(weanling phase) & 0.05% (growing finishing phase) microencapsulated complex of organic acids and essential oils.

^bStandard error.

^cCON vs MOE1 vs MOE2.

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Table 5. Effects of microencapsulated complex of organic acids and essential oils supplementation on nutrient retention in weaning to finishing pigs^a

Item	,%	CON	MOE1	MOE2	SE ^b	Linear ^c	Quadratic ^c
Week 3							
Dry matter		81.82 ^b	82.21 ^b	83.67 ^a	0.46	0.011	0.360
Nitrogen		78.87	78.82	80.47	0.85	0.198	0.422
Energy		80.26	80.5	81.16	0.51	0.230	0.742
Week 6							
Dry matter		72.29 ^b	74.53 ^{ab}	76.63 ^a	1.03	0.007	0.960
Nitrogen		74.08	75.13	76.84	1.00	0.066	0.788
Energy		74.61	75.97	76.51	0.84	0.124	0.692
Week 12							
Dry matter		73.1	73.57	74.36	0.48	0.079	0.787
Nitrogen		72.26	72.21	72.2	0.40	0.925	0.965
Energy		71.34	72.18	72.23	0.39	0.123	0.417
Week 22							
Dry matter		72.06	72.29	73.65	0.75	0.207	0.570
Nitrogen		71.54	71.59	72.46	0.83	0.485	0.721
Energy		70.88	71.26	73.04	0.98	0.128	0.555

Note: Means in the same row with different superscripts differ ($P < 0.05$).

^aAbbreviation: CON, basal diet; MOE1, basal + 0.1% (weanling phase) & 0.025% (growing finishing phase) microencapsulated complex of organic acids and essential oils; MOE2, basal + 0.2% (weanling phase) & 0.05% (growing finishing phase) microencapsulated complex of organic acids and essential oils.

^bStandard error.

^cCON vs MOE1 vs MOE2.

Table 6. The effect of microencapsulated complex of organic acids and essential oils supplementation on the blood profiles in weanling to finishing pigs^a

Item	CON	MOE1	MOE2	SE ^b	Linear ^c	Quadratic ^c
Week 6						
WBC, 10 ³ / μℓ	16.9	17.45	16.73	1.14	0.916	0.658
RBC, 10 ⁶ / μℓ	7.29 ^{ab}	7.8 ^a	7.07 ^b	0.19	0.447	0.020
Lymphocyte, %	52.9	57.8	57.9	3.68	0.354	0.600
IgG, mg/dL	270 ^b	281 ^{ab}	313 ^a	12.1	0.027	0.833
Week 12						
WBC, 10 ³ / μℓ	18.03	18.27	17.93	0.79	0.932	0.774
RBC, 10 ⁶ / μℓ	6.27	6.69	6.63	0.28	0.380	0.508
Lymphocyte, %	42.2	42.2	44.1	6.61	0.846	0.905
IgG, mg/dL	517	583	635	44.42	0.084	0.898
Week 22						
WBC, 10 ³ / μℓ	19.02	19.53	19.04	0.96	0.986	0.679
RBC, 10 ⁶ / μℓ	7.08 ^{ab}	7.54 ^a	6.57 ^b	0.24	0.156	0.030
Lymphocyte, %	42.1	48.5	41.9	6.01	0.982	0.393

Note: Means in the same row with different superscripts differ (P < 0.05).

^aAbbreviation: CON, basal diet; MOE1, basal + 0.1%(weanling phase) & 0.025% (growing finishing phase) microencapsulated complex of organic acids and essential oils; AV2, basal + 0.2%(weanling phase) & 0.05% (growing finishing phase) microencapsulated complex of organic acids and essential oils.

^bStandard error.

^cCON vs MOE1 vs MOE2.

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Table 7. Effect of microencapsulated complex of organic acids and essential oils supplementation on fecal microflora in weanling to finishing pigs^a

Item	CON	AV1	AV2	SE ^b	Linear ^c	Quadratic ^c
Week 6						
<i>Lactobacillus</i>	7.45 ^b	7.52 ^b	7.70 ^a	0.05	0.044	0.045
<i>E.coli</i>	5.32	5.28	5.18	0.22	0.668	0.915
Week 12						
<i>Lactobacillus</i>	7.49	7.5	7.47	0.03	0.702	0.682
<i>E.coli</i>	6.06	6.18	6.19	0.05	0.108	0.366
Week 22						
<i>Lactobacillus</i>	7.46	7.51	7.48	0.02	0.471	0.154
<i>E.coli</i>	6.08	6.01	5.98	0.04	0.121	0.655

Note: Means in the same row with different superscripts differ ($P < 0.05$).

^aAbbreviation: CON, basal diet; MOE1, basal + 0.1%(weanling phase) & 0.025% (growing finishing phase) microencapsulated complex of organic acids and essential oils; AV2, basal + 0.2%(weanling phase) & 0.05% (growing finishing phase) microencapsulated complex of organic acids and essential oils.

^bStandard error.

^cCON vs MOE1 vs MOE2.

Table 8. Effect of microencapsulated complex of organic acids and essential oils supplementation on carcass traits in weanling to finishing pigs^a

Item	CON	MOE1	MOE2	SE ^b	Linear ^c	Quadratic ^c
Backfat						
thickness,	21.50	22.40	22.40	0.38	0.117	0.361
mm						
LMP, %	53.27	53.55	54.68	0.54	0.069	0.521

^aAbbreviation: CON, basal diet; MOE1, basal + 0.1%(weanling phase) & 0.025% (growing finishing phase) microencapsulated complex of organic acids and essential oils; MOE2, basal + 0.2%(weanling phase) & 0.05% (growing finishing phase) microencapsulated complex of organic acids and essential oils.

^bStandard error.

^cCON vs MOE1 vs MOE2.

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Table 9. The effect of microencapsulated complex of organic acids and essential oils supplementation on the meat quality in weanling to finishing pigs^a

Item	CON	MOE1	MOE2	SE ^b	Linear ^c	Quadratic ^c
Meat color						
L*	55.65	56.03	54.31	1.00	0.210	0.254
a*	16.47 <i>a</i>	15.40 <i>b</i>	15.55 <i>b</i>	0.33	0.028	0.075
b*	5.85	5.50	5.31	0.23	0.133	0.793
Sensory						
evaluation						
n						
Color	2.92	3.00	2.86	0.16	0.770	0.539
Firmness	1.04	1.08	1.04	0.14	1.000	0.535
Marbling	1.04	1.12	1.20	0.08	0.195	1.000
Cooking						
loss, %	45.15	40.87	40.31	1.97	0.176	0.528
Drip loss, %						
d1	1.32	1.38	1.48	0.27	0.531	0.923
d3	4.46	3.92	3.75	0.39	0.122	0.618
d5	8.16	6.42	6.64	0.57	0.098	0.201
d7	13.35 <i>a</i>	10.21 <i>b</i>	10.77 <i>b</i>	0.73	0.026	0.054
pH	5.26	5.28	5.31	0.03	0.253	0.899
Longissimus						
muscle	48.81	48.86	49.53	0.65	0.532	0.752
area,cm ²						
Water holding						
capacity,	54.68	49.74	53	1.70	0.535	0.105

%

Note: Means in the same row with different superscripts differ ($P < 0.05$).

^aAbbreviation: CON, basal diet; MOE1, basal + 0.1%(weanling phase) & 0.025% (growing finishing phase) microencapsulated complex of organic acids and essential oils; MOE2, basal + 0.2%(weanling phase) & 0.05% (growing finishing phase) microencapsulated complex of organic acids and essential oils.

^bStandard error.

^cCON vs MOE1 vs MOE2.

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