Comparison of the Efficacy of Different Organic Acids on Growth Performance and Nutrient Digestibility in Weaned Pigs

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다양한 유기산제들의 급여가 이유자돈의 성장과 영양소 소화율에 미치는 효과

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요 약

본 연구는 다양한 유기산제들의 급여가 이유자돈의 성장과 영양소 소화율에 미치는 영향을 비교하기 위하여 2번의 사양실험을 수행하였다. 실험 1과 실험 2에서는 각각 이유자돈 180두(4처리, 3반복, 15두/반복)를 공시하였다. 실험 1은 기초사료에 formic acid, ammonium-formate, lactic acid 그리고 acid mixture를 각각 0.5%씩 첨가하여 총 5주간 사양실험을 실시하였으며, 실험 2는 formic acid, ammonium-formate, lactic acid 그리고 acid mixture를 각각 0.3%씩 첨가하여 총 6주간 사양실험을 실시하였다. Acid mixture는 formic acid와 lactic acid가 50:50의 비율로 혼합된 제제를 사용하였다. 외관상 회장아미노산 소화율을 측정하기 위하여 각 처리별 3두, 총 12두를 공시하여 T-cannula를 회장 말단부에 부착시킨 후 적응기간을 거쳐 회장내용물을 채취하였다. 사양성적은 유기산 종류에 따른 개선 효과는 없는 것으로 나타났으나(실험 1), acid mixture 급여구에서 증체량이 lactic acid 급여구보다 높은 것으로 나타났다(실험 2). 외관상 회장 아미노산 소화율은 lactic acid 급여구보다 acid mixture 급여구에서 개선되는 것으로 나타났다(실험 1과 2). 실험 1과 2의 결과를 종합하였을 때 acid mixture (formic acid + lactic acid) 급여는 이유자돈의 사양성적과 외관상 회장 아미노산 소화율을 개선시키는 것으로 판단된다.

(**Key words :** Organic acids, Efficacy, Growth, Digestibility, Weaned pigs)

Ⅰ. INTRODUCTION

Organic acids have been used for decades as preservatives for compound feeds and their raw materials due to their excellent antifungal activity. They can suppress the growth of moulds, yeast and bacteria, and therefore prevent the formation of mycotoxins (Eidelsburger, 2001). Since 1970, many studies have been conducted on feeding of various organic acids to pigs, especially to weaning pigs to improve nutrient digestibility and reduce post-weaning stress (Tsiloyiannis et al., 2001) and thus improve animal growth performance (Partanen and Mroz, 1999).

The addition of organic acids and their salts to diets for pigs has been reported to increase their performance (Paulicks et al., 1996; Kirchgessner et al., 1997) and to decrease the intra-luminal concentration of coliform bacteria, known to be involved in digestive disorders, and other microorganisms in the gastrointestinal tract (Hansen et al., 2007; Øverland et al., 2007). Salts of organic acids have advantage over free acids because they are generally odorless and easier to handle in the feed-manufacturing process, owing to their solid and less-volatile form. They are also less corrosive and more soluble in water than free acids (Partanen and Mroz, 1999). But free organic acids are more effective both in feed and the gastro-intestinal tract because of their extra effect of acidification. The antimicrobial and growth-promoting effects of organic acids and their salts make them a possible alternative to antibiotics in the diets for pigs (Jensen, 1998; Kommera et al., 2006).

Different organic acids have demonstrated varying degree of inhibitory effect on micro-organisms. Formic acid and lactic acid were effective against bacteria such

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as *Escheerichia coli* and *Salmonella*, whereas lactic acid bacteria were relatively resistant (Knarreborg et al., 2002). However, evaluation of the efficacy of different acids or their mixture in the diets of piglet is scarce. Therefore, the objectives of the present study were to investigate the effects of dietary formic acid, lactic acid, NH_3-formate and acid blends on growth performance, apparent total tract digestibility of nutrients and ileal amino acids in weaned pigs.

Ⅱ. MATERIALS AND METHODS

1. Animals and Diets

All animals were housed and cared for in accordance with the regulations by the Institutional Animal Care and Use Committee of Kangwon National University. Two experiments were conducted in two different commercial farms to evaluate the efficacy of various organic acids or their mixture on growth performance, apparent total tract nutrient and ileal amino acids digestibility in weaned pigs.

In Exp.1, one hundred eighty weanling pigs ((Landrace × Yorkshire) × Duroc; average initial body weight of 6.75 ± 1.16 kg; 21 ± 2 d of age) were assigned to four dietary treatments, each composed of three pens, with 15 pigs (mixed sex) in each pen. The experimental diets were fed for 5 wk in two phases (phase I: 0 to 2 wk, phase II: 3 to 5 wk). Dietary treatments were 0.50% formic acid, 0.50% NH_3-formate, 0.50% lactic acid and 0.50% acid mixture, and organic acids were added in the diets on the weight basis.

In Exp.2, a total of 180 piglets ((Landrace × Yorkshire) × Duroc; average initial body weight of 6.26 ± 1.18 kg; 21 ± 2 d of age)) were allotted to four dietary treatments for 6 wk (phase I: 0 to 2 wk, phase II: 3 to 6 wk) with three replicates containing 15 piglets each (mixed sex). The dietary treatments were 0.30% formic acid, 0.30% NH_3-formate, 0.30% lactic acid and 0.30% acid mixture, and organic acids were included in the diets on the weight basis.

The basal diets were formulated to contain 3,400 kcal ME per kg for both phase I (0 to 2 wk) and phase II (Exp. 1, 3 to 5 wk; Exp. 2, 3 to 6 wk) periods, and lysine content in diet for phase I and phase II was 1.50% and 1.30%, respectively. Other dietary nutrients met or exceeded NRC (1998) recommendations. The ingredient and chemical composition of the basal diets used during both the experiments are presented in Table 1. The organic acids were included in the basal diet at the expense of maize. The concentrations of formic acid and lactic acid were 85%, and NH_3-formate was 65%. Acid mixture comprised of formic acid (85%) and lactic acid (85%) at 50 : 50 ratios. Feed samples taken from every batch were pooled, and subsamples were analyzed for proximate chemical and amino acid compositions.

Table 1 Composition of experimental basal diets (as-fed basis, Exp.1 and 2)

	Phase I (Wk 0 to 2)	Phase II (Wk 3 to 5, Exp.1; Wk 3 to 6, Exp.2)
Ingredients, %		
Maize[1)]	22.53	54.49
Whey power	25.00	–
Soybean meal, 44%	19.56	36.44
Bakery by-product	10.00	–
Lactose	5.00	–
Spray-dried plasma protein	5.00	–
Fish meal	4.00	2.00
Sucrose	4.00	–
Animal fat	–	4.29
Soy oil	2.00	–
Monocalcium phosphate	0.95	–
Dicalcium phosphate	–	0.94
Limestone	0.40	1.01
Zinc oxide	0.34	–
Vitamin premix[2)]	0.30	0.12
Mineral premix[3)]	0.24	0.24
DL-Methionine, 50%	0.30	0.07
L-Lysine HCl, 78%	0.18	0.10
Choline chloride, 25%	0.10	
Salt	0.10	0.30
Chemical composition		
ME[4], kcal/kg	3,400	3,400
Crude protein[5)], %	21.69	21.50
Lysine[5)], %	1.52	1.28
Methionine + Cystine[5)], %	0.84	0.44
Calcium[4)], %	0.80	0.80
Total phosphorus[4)], %	0.72	0.60

1) Organic acids were added to the diets at the appropriate proportion at the expense of maize.
2) Supplied per kilogram of diet : vitamin A, 9,600 IU; vitamin D_3, 1,800 IU; vitamin E, 24 mg; vitamin K_3, 1.5 mg; vitamin B_1, 1.5 mg; vitamin B_2, 12 mg; vitamin B_6, 2.4 mg; vitamin B_{12}, 0.045 mg; pantothenic acid, 24 mg; niacin, 45 mg; biotin, 0.09 mg; folic acid, 0.75 mg; ethoxyquin, 18 mg.
3) Supplied per kilogram of diet : Fe, 150mg; Cu, 96 mg; Zn, 72 mg; Mn, 46.49 mg; I, 0.9 mg; Co, 0.9 mg; Se, 0.3 mg.
4) Calculated values.
5) Analyzed values.

2. Experimental Procedures

All pigs were assigned randomly on the basis of weight to dietary treatments for both experiments. The pigs were housed in partially metal-slotted and concrete floor pens with a pen size of 4.0 × 3.2 m, equipped with a feeder and a drinking nipple in each pen to allow free access to feed and water. The temperature inside the building was maintained with a thermostat-controlled heating and fan ventilation system with constant lighting. The thermostat was set at 30°C for wk 1 and 2 and then lowered by 2°C per wk until it reached 22°C. During the study, individual body weight of weanling pigs and feed disappearance from each pen were recorded at the end of each phase. Average daily gain (ADG), average daily feed intake (ADFI), and feed conversion ratio (FCR) were calculated during the feeding trial.

In order to study the apparent fecal nutrient digestibility, chromic oxide (0.25%) was included as an inert indigestible indicator in all of the diets during different periods. The pigs were fed corresponding diets for 7 days. Fecal grab samples were freely collected from each pen from day 4 to day 7. The fecal samples collected over a 4-day period were pooled to represent one pen. Feces were dried in a forced-air drying oven at 60ºC for 72 h and ground to pass through a 1-mm screen mesh Wiley mill for chemical analysis.

To investigate the effects of different organic acids on apparent ileal amino acids digestibility in Exp. 1 and Exp. 2, representative twelve pigs reflecting the average body weight (3 male pigs per treatment; one each that is representative of each pen) were selected and housed in an individual metabolic cage for the last 2 wk of each experiment. These pigs were fitted with simple ileal T-cannulas according to the method suggested by Walker et al. (1986). The cannula was a rigid, light- weight, yet extremely durable plastic and had an internal diameter of 11 mm. Pigs were given 10 days of adaptation period post-surgery for recovery, during which their daily allowance was gradually increased until the pre-surgical level of feed intake was achieved. This was followed by four days of ileal sample collection. The digesta from the terminal ileum were collected continuously in vinyl bags between 08:00 h and 24:00 h on collection day. Ileal samples were immediately stored at −20ºC, after which it was freeze-dried, then ground with a 1 mm Wiley mill for amino acid analysis.

3. Chemical Analyses

Proximate analyses of the experimental diets and feces samples were carried out following the AOAC (1990) methods. Gross energy was measured by a bomb calorimeter (Model 1261, Parr Instrument Co., Molin, IL) and chromium with an automated spectrophotometer (Jasco V-550, Japan) according to the procedure of Fenton and Fenton (1979). Following acid hydrolysis in 6 N HCl at 110ºC for 24 h, amino acid concentrations were quantified using a HPLC (Waters 486, USA). Sulfur containing amino acids were analyzed after cold performic acid oxidation (Moore, 1963) overnight with subsequent hydrolysis.

4. Statistical Analyses

Values for apparent total tract nutrient and ileal amino acids digestibility were calculated as described previously by Hahn et al. (2006). All data generated were analyzed as a randomized complete block design by using the GLM procedure of SAS software (SAS Inst. Inc., Cary, NC). To determine the efficacy of different organic acids on performance, total tract nutrients and ileal amino acids digestibility, the data were analyzed by one-way ANOVA. Replicate was the experimental unit for all the analysis. The means were separated by using the Duncan's multiple range tests. Probability values less than 0.05 were considered statistically significant.

Ⅲ. RESULTS

Growth performance of pigs fed different organic acids is presented in Table 2 and 3. In Exp.1, there were no differences ($P > 0.05$) in ADG, ADFI, and FCR among the treatments during phase I, phase II and the whole period (Table 2). In Exp.2, no differences ($P > 0.05$) were observed in ADG, ADFI, and FCR due to various organic acids during phase I and II, and the whole period, except for ADG for the whole period (Table 3). Pigs fed with acid mixture had greater ($P < 0.05$) ADG than pigs fed lactic acid diet, while pigs fed with formic acid and NH_3-formate had similar ($P > 0.05$) performance as compared with pigs fed with lactic acid or acid mixture.

During phase I of Exp.1, except for crude fat, the digestibility of all the nutrients was comparable ($P > 0.05$) among the dietary treatments (Table 4). The digestibility of crude fat was higher ($P < 0.05$) in pigs fed acid mixture diet than pigs fed formic acid diet. In phase II, pigs fed lactic acid diet had higher ($P < 0.05$) dry matter and crude protein digestibility when compared

Table 2 Effect of different organic acids on growth performance in weaned pigs (Exp. 1)

Item	Dietary treatments[1)]				SEM[2)]
	Formic acid	NH_3-formate	Lactic acid	Acid mixture	
Wk 0 to 2					
ADG, g	309	341	371	358	18.9
ADFI, g	445	481	548	516	29.4
FCR	1.43	1.40	1.47	1.46	0.03
Wk 3 to 5					
ADG, g	286	343	342	323	16.5
ADFI, g	394	510	525	526	24.9
FCR	1.38	1.48	1.52	1.76	0.08
Wk 0 to 5					
ADG, g	295	342	354	337	12.9
ADFI, g	420	496	537	521	25.3
FCR	1.41	1.44	1.50	1.61	0.04

1) Organic acids were added to diets at 0.50% at the expense of maize. Acid mixture comprised of formic acid (85%) and lactic acid (85%) at 50:50 ratios.
2) Standard error of the mean.

Table 3 Effect of different organic acids on growth performance in weaned pigs (Exp. 2)

Item	Dietary treatments[1)]				SEM[2)]
	Formic acid	NH_3-formate	Lactic acid	Acid mixture	
Wk 0 to 2					
ADG, g	373	353	358	384	12.2
ADFI, g	497	518	509	544	21.4
FCR	1.33	1.47	1.42	1.41	0.03
Wk 3 to 6					
ADG, g	385	393	372	408	7.7
ADFI, g	721	709	725	736	15.9
FCR	1.87	1.81	1.98	1.81	0.06
Wk 0 to 6					
ADG, g	380[ab]	378[ab]	367[b]	399[a]	4.4
ADFI, g	646	645	653	672	12.3
FCR	1.70	1.71	1.78	1.68	0.03

a,b Means with different superscripts in the same row differ ($P < 0.05$).
1) Organic acids were added to diets at 0.30% at the expense of maize. Acid mixture comprised of formic acid (85%) and lactic acid (85%) at 50:50 ratios.
2) Standard error of the mean.

with pigs fed formic acid diet. In addition, the digestibility of crude fat tended to be higher in pigs fed NH_3-formate, lactic acid and acid mixture diets than pigs fed formic acid diet.

During the phase I of Exp.2, the digestibility of dry matter, crude protein and gross energy was comparable ($P > 0.05$) among pigs fed different organic acids; however, pigs fed acid mixture diet had greater ($P < 0.05$) crude fat digestibility when compared with pigs fed NH_3-formate diet (Table 5). In phase II, pigs fed acid mixture diet had higher ($P < 0.05$) dry matter digestibility than pigs fed NH_3-formate and formic acid diets, while pigs fed lactic acid diet had higher ($P < 0.05$) crude protein and gross energy digestibility than pigs fed NH_3-formate and formic acid diets. Moreover, pigs fed NH_3-formate diet had lower ($P < 0.05$) digestibility of dry matter and gross energy when compared with pigs fed lactic acid and acid mixture diets, respectively.

Table 4. Effect of different organic acids on the apparent total tract digestibility of nutrients in weaned pigs (Exp. 1)

Item	Dietary treatments[1)]				SEM[2)]
	Formic acid	NH_3-formate	Lactic acid	Acid mixture	
Phase I (d 14)					
Dry matter, %	83.0	84.7	85.3	84.0	0.72
Gross energy, %	82.4	85.3	85.1	84.6	0.75
Crude protein, %	73.9	76.6	77.0	76.2	1.22
Crude fat, %	63.3[b]	71.1[ab]	69.2[ab]	78.8[a]	2.21
Phase II (d 35)					
Dry matter, %	80.7[b]	83.3[ab]	84.3[a]	82.1[ab]	0.55
Gross energy, %	80.8[b]	83.9[ab]	83.7[a]	81.7[ab]	0.56
Crude protein, %	78.8[b]	82.0[a]	82.5[a]	80.3[a]	0.60
Crude fat, %	64.9	77.2	76.4	75.3	1.79

[a,b] Means with different superscripts in the same row differ ($P < 0.05$).
[1)] Organic acids were added to diets at 0.50% at the expense of maize. Acid mixture comprised of formic acid (85%) and lactic acid (85%) at 50:50 ratios.
[2)] Standard error of the mean.

Table 5. Effect of different organic acids on the apparent total tract digestibility of nutrients in weaned pigs (Exp. 2)

Item	Dietary treatment[1)]				SEM[2)]
	Formic acid	NH_3-formate	Lactic acid	Acid mixture	
Phase I (d 14)					
Dry matter, %	84.0	85.1	84.4	83.9	0.34
Gross energy, %	82.9	84.2	83.4	82.2	0.41
Crude protein, %	74.1	75.2	75.3	72.9	0.52
Crude fat, %	55.7[ab]	49.0[b]	53.7[ab]	60.9[a]	1.86
Phase II (d 42)					
Dry matter, %	74.4[bc]	73.8[c]	77.7[ab]	77.8[a]	0.70
Gross energy, %	76.7[bc]	76.3[c]	80.1[a]	79.6[ab]	0.66
Crude protein, %	74.0[b]	73.5[b]	78.0[a]	77.1[ab]	0.76
Crude fat, %	57.7	64.5	64.6	70.9	2.28

[a,b,c] Means with different superscripts in the same row differ ($P < 0.05$).
[1)] Organic acids were added to diets at 0.30% at the expense of maize. Acid mixture comprised of formic acid (85%) and lactic acid (85%) at 50:50 ratios.
[2)] Standard error of the mean.

The apparent ileal digestibility of essential and nonessential amino acids differed among pigs fed diets supplemented with different organic acids. In Exp.1, the ileal digestibility of essential amino acids was higher ($P < 0.05$) in pigs fed acid mixture and NH_3-formate diets, while pigs fed formic acid diet had the lowest ($P < 0.05$) apparent ileal digestibility of essential and nonessential amino acids (Table 6). More inconsistencies were noticed in the ileal amino acid digestibility during Exp. 2 (Table 7). In general, pigs fed acid mixture supplemented diet had higher ($P < 0.05$) ileal digestibility of essential amino acids except for histidine, isoleucine and threonine. Moreover, pigs fed lactic acid and formic acid diets had lower ($P < 0.05$) digestibility of essential amino acids except for higher methionine digestibility in case of lactic acid fed pigs and higher ($P < 0.05$) isoleucine,

Table 6 Effect of different organic acids on the apparent ileal digestibility of amino acids in weaned pigs (Exp. 1, d 35)

Item	Dietary treatments[1)]				SEM[2)]
	Formic acid	NH_3-formate	Lactic acid	Acid mixture	
Essential amino acids					
Arginine, %	77.3[c]	82.1[b]	78.3[c]	83.5[a]	0.79
Histidine, %	82.0[c]	84.4[b]	84.1[b]	86.5[a]	0.50
Isoleucine, %	76.3[b]	84.0[a]	78.5[b]	86.9[a]	1.41
Leucine, %	77.1[b]	84.3[a]	80.1[b]	87.2[a]	1.26
Lysine, %	86.7[b]	89.4[a]	87.5[ab]	89.2[a]	0.45
Methionine, %	82.7[b]	81.7[bc]	79.9[c]	86.9[a]	0.83
Phenylalanine, %	80.2[c]	86.9[a]	83.0[b]	88.3[a]	0.98
Threonine, %	80.1[d]	87.1[b]	83.9[c]	89.9[a]	1.13
Valine, %	77.9[b]	85.5[a]	78.7[b]	85.9[a]	1.23
Non-essential amino acids					
Alanine, %	73.8[d]	82.7[b]	77.6[c]	86.1[a]	1.46
Aspartic acid, %	76.9[c]	87.6[a]	80.1[bc]	83.5[b]	1.29
Cystine, %	70.7[c]	90.9[a]	86.8[ab]	84.6[b]	2.37
Glutamic acid, %	79.9[c]	88.5[ab]	86.3[b]	89.6[a]	1.18
Glycine, %	79.6[b]	88.0[a]	78.8[b]	89.0[a]	1.55
Proline, %	78.9[ab]	82.8[a]	77.2[b]	82.9[a]	0.91
Serine, %	88.5[ab]	89.2[a]	84.6[bc]	84.0[c]	0.88

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

[1)] Organic acids were added to diets at 0.50% at the expense of maize. Acid mixture comprised of formic acid (85%) and lactic acid (85%) at 50:50 ratios.

[2)] Standard error of the mean.

Table 7 Effect of various organic acids on the apparent ileal digestibility of amino acids in weaned pigs (Exp. 2, d 42)

Item	Dietary treatment[1)]				SEM[2)]
	Formic acid	NH_3-formate	Lactic acid	Acid mixture	
Essential amino acids					
Arginine, %	84.0[b]	86.7[a]	84.1[b]	86.8[a]	0.41
Histidine, %	81.4[c]	83.9[a]	82.6[b]	78.8[d]	0.57
Isoleucine, %	75.5[a]	73.0[b]	65.6[c]	73.1[b]	1.14
Leucine, %	77.8[b]	79.4[ab]	75.6[c]	81.2[a]	0.68
Lysine, %	80.2[a]	74.3[b]	73.6[b]	81.8[a]	1.11
Methionine, %	84.8[b]	88.4[a]	88.4[a]	90.7[a]	0.71
Phenylalanine, %	79.6[b]	81.0[ab]	76.4[c]	81.5[a]	0.64
Threonine, %	79.9[c]	86.9[a]	84.5[b]	85.5[b]	0.80
Valine, %	78.3[a]	77.9[a]	72.7[b]	78.3[a]	0.75
Non-essential amino acids					
Alanine, %	74.5[b]	77.5[a]	70.7[c]	75.4[ab]	0.80
Aspartic acid, %	88.5[a]	79.5[b]	83.1[b]	77.9[b]	1.40
Cystine, %	85.8[a]	80.9[ab]	76.6[bc]	74.4[c]	1.47
Glutamic acid, %	81.8[bc]	80.7[c]	83.4[ab]	85.2[a]	0.61
Glycine, %	78.2[b]	83.5[a]	79.3[ab]	79.4[ab]	0.86
Proline, %	83.6[b]	88.2[a]	87.1[a]	88.8[a]	0.73
Serine, %	89.4[a]	86.1[b]	79.8[c]	75.9[b]	1.61

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

[1)] Organic acids were added to diets at 0.30% at the expense of maize. Acid mixture comprised of formic acid (85%) and lactic acid (85%) at 50:50 ratios.

[2)] Standard error of the mean.

lysine and valine digestibility in pigs fed formic acid diet.

Ⅳ. DISCUSSION

Use of organic acids in piglet feeding is generally focused on their qualitative action, their activity towards reducing coliforms which are considered as harmful for the health status of the gastrointestinal tract. Consequently, these effects are manifested in a better animal health and enhanced nutrient digestibility and improved growth performance (Partanen, 2001).

In the present study there were no differences in the growth performance of pigs fed different organic acids in Exp.1; however, in pigs fed 0.3% acid mixture diet had 8.7% higher gain than pigs fed 0.3% lactic acid diet in Exp. 2. As both the experiments were conducted under commercial conditions, it was interesting to observe differences in growth performances at lower inclusion level (Exp. 2, 0.3%) of organic acids. The greater inclusion rate of acid may contribute to the reduced feed intake, which was observed that the feed intake was lower in Exp.1 as compared with in Exp. 2. Radecki et al. (1988) noted that the addition of citric acid at high level (3%) in the starter pig diet had a negative effect on feed intake when compared with low level (1.5%). Similarly, Walsh et al. (2007) also observed the decreased feed intake in weanling pigs fed different levels of lactic acid (0.4 vs. 0.2%). These differences may also be due to the longer duration of feeding organic acids in Exp. 2 (6 wk) than in Exp. 1 (5 wk).

The mode of action of organic acids in the digestive tract can be divided into two parts, acidification and the action of an anion of the organic acid (Eidelsburger, 2001). The acidification of the feed using organic acids mainly influences the digestive processes in the stomach of weaned piglets that still have limited capacity for production of HCl (Risley et al., 1992; Hansen et al., 2007). The influence of the anions of organic acids can be demonstrated mainly in the small intestine, where it combines with other cations and inhibits growth of harmful microbes. Many studies have demonstrated the positive influence on growth perfor- mance due to supplementation of organic acids (Omogbenigun et al., 2003; Walsh et al., 2007). However, Skirrow et al. (1997) did not observe any effect on growth performance of pigs fed organic acid supplemented diets. The overall ADG was higher in acid mixture added diet than lactic acid fed animals only in Exp.2, but it was not different than formic acid and ammonium formate group. This could be better explained as a synergistic effect due to the combination of formic and lactic rather than an individual effect especially when lactic acid is concerned. In line with these findings, Partanen et al. (2002) found that formic acid-sorbate blend had superior growth than that of formic acid addition in growing-finishing pigs. The improvement of growth performance might be related with the reduction of microbial populations in the stomach and small intestine when the acid mixture was added to the weaned pig diets. Franco et al. (2005) observed that formic : lactic combinations reduced coliforms counts in the small intestine, while the numbers of lactobacilli remained unaffected. The variable effects of different organic acids can be attributed to their differences in dietary buffering capacity, dosage, combination of feed ingredients and additives, weanling age and feeding duration.

The relative lower fat digestibility observed in Exp.2 than in Exp. 1 might be due to the less inclusion of organic acids in the diets. Similar findings were also noted by Eidelsburger et al. (2001), where linear improvement of apparent fecal fat digestibility was found in weaned pigs with the increasing of supplemented with formic acid from 0 to 1.8% to the diets. The reduction of CP digestibility is presumed to be related to the inadequate HCl secretion in the stomach of early-weaned pigs. A high gastric pH would cause a reduction in the activation of pepsin, which occurs rapidly at pH 2 and very slowly at pH 4. Pepsin I has an optimal activity at pH 2 and pepsin II has an optimal activity at pH 3.5 (Geary et al., 1999). Organic acids can reduce pH rapidly in the piglets that still cannot secrete sufficient HCl to maintain a low pH in the stomach, which can improve the activation of pepsinogen and pepsin (Canibe et al., 2001). Subsequently, organic acids have a positive influence on the digestibility of protein (Franco et al., 2005; Guggenbuhl et al., 2007). Furthermore, due to the reduction of deamination of amino acid in the stomach following addition of organic acids to the feed, more amino acids are available for absorption and ultimate protein retention, and the energy necessary for conversion of ammonia to urea in the liver and the renal release of urea is available for metabolism. In the end, the digestibility of gross energy has been increased (Eidelsburger, 2001). In the Exp.1, the lactic acid addition resulted in improvement of CP digestibility in pigs 5 wk postweanling than that of formic acid inclusion. Similarly, in the Exp.2, dietary lactic acid supplementation improved the digestibilities of crude protein and gross energy in pigs 6 wk postweanling than the treatment added with formic acid. However, no differences between these two treatments were noted on apparent nutrient utilization 2 wk after weanling in both experiments, while the nutrients digestibility was numerically higher with the inclusion of acid blends. Possible explanations for success of lactic acid or acid mixture over that of formic acid may lie in the ability of organic acids to exert their most beneficial effects after 2 wk of postweanling.

The dietary organic acid mixture improved the ileal apparent digestibility of amino acids than those of different organic acids used alone in weaned pigs. Improved ileal amino acid apparent digestibilities have been reported when diets for growing-finishing pigs have been supplemented with propionic (Mosenthin et al., 1992), lactic (Kemme et al., 1999), formic (Partanen et al., 2001), butyric, or fumaric acid (Mroz et al., 2000). In the present experiment, the ileal amino acid apparent digestibilities were improved by 1.61% to 13.88%. Somewhat less improvements were reported in the aforementioned studies, which could have been a result of differences in the acid added and the inclusion levels used and diet composition. Another reason for improved apparent ileal amino acid digestibilities seen in diets supplemented with organic acid might be explained that acidification could lead to greater responses in early-weaned pigs due to the immaturity of their digestive tract instead of growing-finishing pigs, which have the mature digestive hindgut. Dietary acids function in the upper portion of the gastro intestinal tract resulted in a reduction of gastrointestinal pH and an improvement of protease activation at this time. Partanen et al. (2007) noted that addition of 0.84% organic acid mixture (formic acid, sorbate and benzoate) to pig diets had improved the apparent ileal digestibility of almost amino acids. In contrast, Gabert et al. (1995) did not found any effect of formic acid supplementation on apparent ileal digestibilities of amino acids for early-weaned pigs.

The results of this study demonstrated that feeding acid mixture (50 : 50 ratios of dietary formic acid and lactic acid) to weaned pigs is an effective means of improving growth performance and enhancing apparent nutrient digestibility. Moreover, the results also indicate that feeding mixture of dietary formic acid and lactic acid is more efficient than individual supplementation. However, further work is needed to investigate the synergistic effect of combining different organic acids on gastrointestinal pH and microbial populations in weaned pigs.

Ⅴ. ABSTRACT

Two experiments were conducted to compare the effects of different organic acids on growth performance and apparent nutrients digestibility in weaned pigs. In both the experiments, 180 pigs were assigned to four treatments with three replicates comprising of 15 pigs in each. Formic acid, ammonium-formate, lactic acid, and acid mixture were added to diets at 0.50% (Exp. 1) and 0.30% (Exp. 2) as dietary treatments for 5 and 6 wk feeding trial, respectively. The acid mixture was prepared by mixing formic acid and lactic acid at 50:50 ratios. To investigate the apparent ileal amino acids digestibility, twelve pigs (3 per treatment) were used and fitted with simple ileo-caecal T-cannula for both experiments. In Exp.1, growth performance was comparable ($P>0.05$) among pigs fed different organic acids, while acid mixture had higher ($P<0.05$) weight gain than that of lactic acid in Exp.2. The apparent ileal digestibility of amino acids was highest ($P<0.05$) in pigs fed acid mixture and lowest ($P<0.05$) in pigs fed formic acid diets in both experiments. These results indicated that supplementation with acid mixture (formic acid and lactic acid) improved performance and ileal amino acid digestibility in weaned pigs.

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