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Effect of fumaric acid, calcium formate and mineral levels in diets on the intake and growth performance of newly weaned pigs

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The weaned pig has limited ability to acidify its stomach contents. The objective of this study (comprising three experiments) was to examine the effect of feeding diets containing fumaric acid (FA), calcium formate (CF) or diets of low acid binding capacity (ABC) on post-weaning pig performance. In all three experiments, pigs (10 per treatment) were weaned at 19 to 24 days, blocked on sex and weight and assigned at random to one of six treatments. In Experiment 1, treatments were: (1) control diet, (2) control + 20 g/kg FA, (3) control + 15 g/kg CF, (4) low Ca (2.8 g/kg) and P (5.1 g/kg) (LCaP) diet for seven days followed by the control diet, (5) LCaP diet for seven days followed by control + 20 g/kg FA, and (6) LCaP diet for seven days followed by control + 15 g/kg CF. In Experiment 2, treatments were: (1) control diet, (2) control + 20 g/kg FA, (3) control + 15 g/kg CF, (4) LCaP diet for 14 days followed by the control diet, (5) LCaP diet for 14 days followed by control + 20 g/kg FA, and (6) LCaP diet for seven days followed by control diet. In Experiment 3, treatments were: (1) high Ca (HC) diet (12 g/kg), (2) medium Ca (MC) diet (9 g/kg), (3) low Ca (LC) diet (6 g/kg), (4) HC + 20 g/kg FA, (5) MC + 20 g/kg FA, and (6) LC + 20 g/kg FA. Pigs were individually fed for 26 days. In Experiment 1, CF tended to depress daily feed intake (DFI) in the final two weeks (691 v. 759 and 749, (s.e. 19) g/day, $P = 0.07$) and overall average daily gain (322 v. 343 and 361 (s.e. 11) g/day, $P = 0.09$) compared with the control and FA supplemented diets, respectively. Feeding diets with LCaP for seven days post weaning increased DFI (208 v. 178, (s.e. 8) g/day, $P < 0.01$) in week 1 and tended to improve feed conversion rate in the first two weeks (1.65 v. 1.85, s.e. 0.10, $P = 0.09$). In Experiment 2, treatment had no significant effect on pig performance but feed

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conversion rate in weeks three and four was improved for Treatment 5 compared with Treatment 4 (1.30 v. 1.39 (s.e. 0.06) g/g, P < 0.01). In experiment 3, FA increased (P < 0.05) pig weight at day 14 (8.4 v. 7.7 (s.e. 0.2) kg) and feed intake in weeks one and two (223 v. 251, (s.e. 9) g/day). It is concluded that CF did not improve performance but reducing diet ABC or including FA in the diet did improve performance.

Keywords: Acid binding capacity; calcium formate; fumaric acid; pig; weaning

Introduction

Fumaric acid (FA) inclusion in diets for newly weaned pigs has been found to benefit pig performance (Giesting and Easter, 1985; Radecki *et al.,* 1988; Giesting *et al.,* 1991). These benefits are most pronounced when diets with low levels of milk by-products are used (Lawlor, 1992). Dairy products contain lactose, which is fermented to lactic acid in the stomach, thus reducing the pH of the gut contents (Kidder and Manners, 1978; Easter, 1988) and diet acidification using feed acids such as FA is unlikely to have further benefit. Calcium formate (CF) has also been used for acidification with some success (Kirchgessner and Roth, 1990).

The acid binding capacity (ABC) of a feed can influence the pH in the piglet stomach. The dietary ABC value is influenced by feed type, protein level, fibre level, mineral composition and type as well as particle size (Lawlor, 1992; Lawlor *et al.,* 2005a). Bolduan *et al.* (1988) suggested that feeding diets with low ABC values can be used in the same way as organic acids to maintain adequate acidity in the stomach. These authors also suggested that using a starter diet with a maximum mineral supplementation of 10 g/kg could help achieve a diet of low ABC because alkaline components of a mineral mixture such as $CaCO_3$ have a particularly high ABC (BASF, 1989; Jasaitis *et al.,* 1987).

The objective of this study was to examine the effect of CF and FA in diets with either normal or reduced Ca and P levels on the intake and growth performance of newly weaned pigs.

Materials and Methods

The pigs used in these experiments were the progeny of sire line boars (Pig Improvement Associates (PIA), Blessington, Co. Wicklow) and F1 sows (Large white × Landrace; PIA). The ingredient composition and chemical analysis of the experimental diets are presented in Table 1.

Experiment 1

At weaning (22, s.e. 0.3, days) pigs (30 males and 30 females) were blocked on sex and weight and assigned at random to six treatments as follows: (1) normal (NRC, 1998) Ca and P (NCaP) diet (Diet 1), (2) NCaP diet with 20 g/kg FA (Diet 2), (3) NCaP diet with 15 g/kg CF (Diet 3), (4) low Ca and P (LCaP) diet (Diet 4) for 7 days followed by Diet 1, (5) LCaP diet (Diet 4) for seven days followed by Diet 2, (6) LCaP diet (Diet 4) for seven days followed by Diet 3. The duration of the experiment was 28 days.

Experiment 2

At weaning (22, s.e. 0.4, days) pigs (30 male and 30 female) were blocked on sex and weight and assigned at random to six dietary treatments as follows: (1) NCaP diet (Diet 1), (2) NCaP diet with 20 g/kg FA (Diet 2), (3) NCaP diet with 15 g/kg CF (Diet 3), (4) LCaP diet (Diet 4) for 14 days followed by Diet 1, (5) LCaP diet

Table 1. Ingredient composition and chemical analysis of experimental diets

	Diet number									
	1	2	3	4	5	6	7	8	9	10
Composition (g/kg)										
Barley	160	160	160	160	160	160	160	160	160	160
Wheat	459	439	456	481	451.5	459.5	467.5	431.5	439.5	447.5
Dried whey	50	50	50	50	50	50	50	50	50	50
Herring meal	50	50	50	50	50	50	50	50	50	50
Soya full fat	125	125	125	125	125	125	125	125	125	125
Soya bean meal	100	100	100	100	100	100	100	100	100	100
Soya oil	20	20	20	20	20	20	20	20	20	20
L-Lysine monohydrochloride	2	2	2	2	2	2	2	2	2	2
DL-Methionine	1	1	1	1	1	1	1	1	1	1
L-Threonine	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Di calcium phosphate	10	10	10	–	10	10	10	10	10	10
Limestone flour	12	12	–	–	19	11	3	19	11	3
Salt	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Vitamins and minerals[1]	3	3	3	3	3	3	3	3	3	3
Spiratet[2]	4	4	4	4	4	4	4	4	4	4
Mould curb[3]	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Fumaric acid	–	20	–	–	–	–	–	20	20	20
Calcium formate	–	–	15	–	–	–	–	–	–	–
Chemical analysis										
Dry matter (g/kg)	886	888	888	886	884	883	883	886	886	884
Ash (g/kg)	56.2	55.4	55.2	39.0	60.0	53.0	46.9	57.0	52.3	46.7
Fat (g/kg)	65.3	64.8	66.2	67.8	60.5	64.5	61.5	60.0	61.0	62.0
Crude fibre (g/kg)	33.5	32.0	31.4	32.6	31.3	32.0	33.0	31.7	34.0	33.0
Crude protein (g/kg)	207	207	206	211	215	217	214	210	210	211
Digestible energy (MJ/kg)	14.5	14.4	14.4	14.8	144	145	146	143	144	146
Lysine (g/kg)	12.8	12.7	12.7	12.9	12.8	12.8	12.8	12.7	12.7	12.8
Calcium (g/kg)	9.5	9.5	9.4	2.8	12.0	9.0	6.0	12.0	9.0	6.0
Phosphorus (g/kg)	7.0	7.0	6.9	5.1	7.0	7.0	7.0	6.9	6.9	6.9
Diet acidity										
Diet pH	6.88	4.57	5.90	6.77	7.00	7.00	7.05	4.90	4.85	4.77
ABC-4 (meq HCl/kg)[4]	315	180	310	207	500	390	340	300	270	194
ABC-3 (meq HCl/kg)[5]	650	600	680	430	840	680	600	690	660	570

[1]Provided per kilogram of complete diet: Cu, 175 mg; Fe, 140 mg; Mn, 47 mg; Zn, 120 mg; I, 0.6 mg; Se, 0.3 mg; vitamin A, 6000 IU; vitamin D_3, 1000 IU; vitamin E, 100 IU; vitamin K, 2 mg; vitamin B_{12}, 15 μg; riboflavin, 2 mg; nicotinic acid, 12 mg; pantothenic acid, 10 mg; choline chloride, 250 mg; vitamin B_1, 2 mg; vitamin B_6, 3 mg; and endox, 60 mg.
[2]Spiratet: 75 g oxytetracycline and 25 g spiramycin per kg.
[3]Product of Kemin Industries Inc, Des Moines, Iowa, USA.
[4]Acid binding capacity to a titration end point of pH 4 (Lawlor *et al.,* 2005a).
[5]Acid binding capacity to a titration end point of pH 3 (Lawlor *et al.,* 2005a).

(Diet 4) for 14 days followed by Diet 2, (6) LCaP diet (Diet 4) for seven days followed Diet 1. The duration of the experiment was 28 days.

Experiment 3

At weaning (22, s.e. 0.3, days) pigs (30 male and 30 female) were blocked on sex and weight and assigned at random to six dietary treatments as follows: (1) high Ca (HC) diet (Diet 5), (2) medium Ca (MC) diet (Diet 6), (3) low Ca (LC) diet (Diet 7), (4) HC diet with 20 g/kg FA (Diet 8), (5) MC diet with 20 g/kg FA (Diet 9), (6) LC diet with 20 g/kg FA (Diet 10). The MC diet was formulated to adequately meet NRC (1998) requirements for Ca; the HC diet had an excessive concentration of Ca while the LC diet was deficient. The duration of the experiment was 28 days.

Housing and management

Pigs were penned individually in fully slatted pens (0.6 m × 0.9 m) in a two level facility. Temperature control was by a hot air heating system and an exhaust fan, both controlled by a thermostat. Temperature was maintained at 28 °C in the first week and reduced by 2 °C per week to 22 °C in the fourth week post weaning. Lighting was by tubular fluorescent lights for 8 h per day. Pigs were observed closely twice daily. Any pig showing signs of ill-health was treated as appropriate. Feeders and drinkers were checked daily and cleaned or adjusted as required.

Feeding

Pigs were offered feed *ad libitum* with care taken to avoid wastage. Feed was offered in a 0.6 m long stainless steel trough. Water was available *ad libitum* from nipple drinkers (one per pig). Pigs in all experiments were offered a commercial creep feed in the farrowing house from 10 days of age until weaning. The quantity of creep feed consumed by individual litters was not recorded but previous work at this centre has shown it to be approximately 1 kg per litter to weaning at 19 to 24 days of age.

Feed manufacture and analysis

Feed was manufactured in the Moorepark feed mill. Cereals were ground through a 3 mm screen before mixing. The experimental diets were offered in meal form.

Representative samples of all diets were taken after mixing. Dry matter, crude fibre, crude protein, ash and oil analysis were performed as described by Lawlor *et al.* (2002). Acid binding capacity and pH of the experimental diets were also performed as previously reported (Lawlor *et al.,* 2005a).

Statistical analysis

Each experiment was analysed using general linear model procedures (SAS, 1996) for a randomised complete block design with the pig as the experimental unit.

In Experiment 1, the three types of acidifiers and two levels of minerals were analysed as a 3 × 2 factorial. The model used had effects for block, type of acidifier, level of minerals, and the interaction of acidifier × mineral level.

In Experiment 2, the model used had effects for block and treatment. Contrasts were used to separate means for: (1) normal Ca and P levels (NCaP) versus low Ca and P levels (LCaP) in the early post-weaning period, (2) feeding the LCaP diet for either 7 or 14 days followed by the NCaP diet, and (3) feeding the LCaP diet for 14 days followed either by the NCaP diet or the NCaP diet plus FA.

In Experiment 3, the two levels of FA and three levels of minerals were analysed as a 2 × 3 factorial. The model used had effects for block, level of FA, level of minerals, and the interaction of FA × mineral level. Weaning weight was used as a covariate in the model.

Results

Acid binding capacity and pH of the experimental diets are presented in Table 1. The results for Experiments 1, 2 and 3 are presented in Tables 2, 3 and 4, respectively.

Table 2. Performance of pigs fed diets with two levels of calcium and phosphorous and supplemented with acidifiers (Experiment 1)

	Treatment[1]						s.e	Significance	
	1	2	3	4	5	6		Acidifier	Mineral level
Pig weight (kg)									
Weaning	6.1	6	6	6	5.8	6.1	0.1		
Day 14	8.2	9	8.2	8.7	8.7	8.7	0.3		
Final	15.1	15.9	14.4	15.5	15.4	15.1	0.5		
Feed intake (g/day)									
Week 1[3]	162	206	164	210	204	210	11		**
Week 2	401	438	402	419	416	396	22		
Week 3	674	707	599	737	710	673	32	P < 0.08	P < 0.08
Week 4	822	817	751	819	775	757	35		
Weeks 1–2	282	322	283	315	310	303	15		
Weeks 3–4	742	758	669	775	740	712	28	P < 0.07	
Overall	504	532	469	536	517	500	19		
Daily gain (g/day)									
Weeks 1–2	154	212	159	196	206	188	17	P < 0.09	
Weeks 3–4	531	533	474	518	517	491	21		
Overall	335	367	311	351	356	334	16	P < 0.09	
Feed conversion rate[2] *(g/g)*									
Weeks 1–2	1.97	1.65	1.93	1.72	1.53	1.69	0.15		P < 0.09
Weeks 3–4	1.4	1.44	1.41	1.51	1.44	1.45	0.05		
Overall	1.5	1.47	1.53	1.55	1.46	1.5	0.04		

[1]Involved diets with normal (treatments 1 to 3) and low (treatments 4 to 6) Ca and P concentrations supplemented with 20 g/kg fumaric acid (treatments 2 and 5) or with 15 g/kg calcium formate (treatments 3 and 6). See text for details.

[2]Feed/gain.

[3]Significant interaction between effects of calcium concentration and fumaric acid level for feed intake in week 1 (P < 0.05).

Experiment 1

In general, the health of pigs was good. One pig from Treatment 6 was treated for a skin rash by injecting with Ivermectin (Ivomec, MSD AGVET, Haarlem, Netherlands) and washing with antiseptic solution (Savlon, Novartis Consumer Health, Horesham, UK). In the first week, two pigs were treated for scour, one from Treatment 3 and the other from Treatment 5. One pig from Treatment 1 was also treated for scour in the second week.

Only in week 1 of the experiment was an interaction (P < 0.05) observed when FA inclusion increased feed intake on the NCaP diet but not on the LCaP diet.

During the initial two-week period, pigs offered the FA supplemented diets ate proportionately 0.06 more feed than pigs given the basal diet but this difference was not significant. CF tended to reduce feed intake in the final two weeks (P = 0.07). For the overall experimental period, CF inclusion was associated with a reduction (proportionately 0.07) in feed intake but the difference was not significant. Feed intake for FA fed pigs was similar to that of pigs fed the basal diet in the final two weeks and overall.

Daily gain tended to increase (P = 0.09) during the initial two weeks of the experiment when FA was included in the diet. In the final two-week period, daily

Table 3. Performance of weaned pigs fed normal (NCaP) or low calcium and phosphorus (LCaP) diets with or without fumaric acid (FA) or calcium formate (CF) (Experiment 2)

	Treatment[1]						s.e.[3]
	1	2	3	4	5	6	
Pig weight (kg)							
Weaning	6.1	6.2	6.2	6.2	6.1	6.1	0.1
Day 14	8.8	9.2	9.1	9.2	9.3	9.1	0.2
Final	15.3	15.8	15.4	15.5	16	15.3	0.4
Feed intake (g/day)							
Week 1	217	208	193	204	229	235	16
Week 2	384	401	395	395	439	423	20
Week 3	605	612	629	636	619	625	22
Week 4	733	733	719	724	717	694	35
Weeks 1–2	301	305	294	299	334	329	16
Weeks 3–4	651	668	670	676	664	657	25
Overall	469	479	475	481	493	487	19
Daily gain (g/day)							
Weeks 1–2	196	212	206	212	229	219	16
Weeks 3–4	501	508	490	484	514	471	17
Overall	343	355	343	343	366	340	15
Feed conversion rate[2] (g/g)							
Weeks 1–2	1.56	1.47	1.46	1.43	1.48	1.55	0.06
Weeks 3–4	1.30	1.33	1.38	1.39	1.3	1.4	0.04
Overall	1.37	1.36	1.4	1.4	1.36	1.44	0.03

[1]Involved diets with normal Ca and P concentrations (treatments 1 to 3) supplemented with 20 g/kg fumaric acid (treatment 2) or with 15 g/kg calcium formate (treatment 3) and diets with low Ca and P concentrations fed for 2 weeks followed by diets with normal Ca and P concentrations in weeks 3 to 4 without (treatment 4) or with (treatment 5) 20 g/kg fumaric acid. Treatment 6 involved feeding a diet with low Ca and P concentrations in week 1 followed by a diet with normal Ca and P concentrations during weeks 2 to 4. See text for details.
[2] Feed/gain.
[3]There was no significant difference for the following contrasts NCaP v. LCaP; PCaP for 14 days v. 7 days; LCaP for 14 days followed by NCaP with FA v. LCaP for 14 days followed by NCaP without FA.

gain of pigs offered the FA and basal diets was similar but the daily gain of CF supplemented pigs was numerically lower by proportionately 0.08 ($P > 0.05$). For the overall period FA inclusion tended to increase daily gain while CF tended to reduce daily gain ($P = 0.09$).

The feed conversion rate of pigs offered the FA diet was numerically improved by proportionately 0.14 and 0.04 in the initial two-week period and for the overall period, respectively, but these differences were not statistically significant. Feed conversion rate was not influenced in any period of the experiment by the inclusion of CF in the diet.

Feed intake was greater during week 1 ($P < 0.01$) and week 3 ($P = 0.08$) for pigs which had been offered the LCaP diet for the first week than those on the NCaP diet. The daily gain of pigs on the LCaP diet also tended to be higher in the initial two weeks of the experiment (proportionately 0.13) as well as for the overall experiment (proportionately 0.03) but these differences were not statistically significant. Feed conversion rate of pigs on the LCaP diet tended to improve in the initial two-week period ($P = 0.09$) relative to that of pigs on the NCaP diet. This benefit was lost in the final two weeks so that feed conversion rate for those diets was similar overall.

Table 4. Effect of fumaric acid on performance of weaned pigs fed diets with different calcium levels (Experiment 3)

	Treatment[1]						s.e.	Significance[3]	
	1	2	3	4	5	6		Fumaric acid	Calcium
Pig weights (kg)									
Initial	6.1	6.1	6.1	6.1	6.1	6.1	0		
Day 14	7.3	7.9	7.8	8.6	8.1	8.4	0.3	*	
Final	13.9	14.1	14.3	15.4	14.1	15	0.5		
Feed intake (g/day)									
Week 1	143	151	183	211	169	189	12.1	**	
Week 2	281	284	287	306	294	342	23.5		
Week 3	541	548	548	602	521	608	31.4		
Week 4	632	640	639	702	608	710	36.7		
Weeks 1–2	213	236	219	258	232	265	15.1	*	
Weeks 3–4	624	641	654	701	619	693	31.8		
Overall	411	431	428	471	418	471	21.5		
Daily gain (g/day)									
Weeks 1–2	110	140	131	172	144	164	20	$P<0.09$	
Weeks 3–4	525	504	545	580	498	556	26		
Overall	291	296	304	346	299	330	19		
Feed conversion rate[2] (g/g)									
Weeks 1–2	3.69	2.17	2.95	1.58	2.11	2.48	0.90	$P<0.10$	
Weeks 3–4	1.21	1.34	1.22	1.19	1.26	1.27	0.03		$P<0.08$
Overall	1.45	1.55	1.46	1.34	1.43	1.46	0.05	$P<0.11$	

[1]Involved diets supplemented with 0 g/kg (treatments 1 to 3) and 20 g/kg (treatments 4 to 6) fumaric acid with high (1.2 g/kg; treatments 1 and 4), medium (0.9 g/kg; treatments 2 and 5) or low (0.6 g/kg; treatments 3 and 6) concentrations of calcium. See text for details.

[2] Feed/gain.

[3]Significant interaction between effects of calcium concentration and fumaric acid level for feed intake in week 1 ($P < 0.05$).

Experiment 2

Pig health over the duration of this Experiment was excellent and no veterinary intervention was required.

Treatment had no significant effect on pig weight, feed intake, daily gain or feed conversion rate for any period of the experiment.

Experiment 3

It was necessary to remove four pigs from Experiment 3. One pig on Treatment 1 was removed at the end of week 1 because of a swollen testicle. Two pigs on Treatment 3 and one on Treatment 2, were removed after seven days due to refusal to eat. Two pigs from Treatment 1, one each from Treatments 3 and 4 were treated for scour in the first 7 days.

No significant interaction between acid usage and calcium level in the diet was observed for pig weight, daily gain or feed conversion rate. A significant interaction for feed intake was observed in week 1. Feed intake of pigs fed a diet with no acid increased as Ca level of the diet was reduced; however, feed intake of FA-fed pigs was greatest on the HC diet.

Effect of FA addition on piglet performance

The addition of FA to the diet increased the feed intake by proportionately 0.19 in the first week ($P < 0.01$). Over the first 14 days FA-fed pigs ate proportionately 0.13

more than control pigs ($P < 0.05$). Intakes of the FA-fed pigs over the entire experiment were proportionately 0.07 higher, but this was not significant.

Daily gain of acid supplemented pigs increased proportionately by 0.26 over the initial 14 day period ($P = 0.09$). At day 14, pigs on FA diet were proportionately 0.09 heavier than the control animals ($P < 0.05$). The daily gain by pigs on FA diet for the overall experiment, as well as final pig weight, were also higher by proportionately, 0.09 and 0.05, respectively, but these differences were not significant.

Feed conversion rate for the first two weeks tended to be better in FA-fed pigs ($P = 0.10$). Although the feed conversion rate of pigs on diets with and without FA were almost identical in the last two weeks, a numerical improvement ($P = 0.11$) of proportionately 0.05 in feed conversion rate was recorded with FA-fed pigs for the overall period.

At no stage during the experiment was pig weight, feed intake or daily gain influenced by the level of calcium in the diet. Feed conversion rate tended to improve over the final two-week period ($P = 0.08$) when HC or LC diets were fed.

Discussion

The ABC values obtained for the experimental diets were in line with those expected. Lawlor *et al*. (2005a) previously found a good relationship between predicted and observed ABC values for pig diets (R^2 0.7 to 0.8). Both FA addition and the omission of Ca and/or P from the diet reduced ABC-3 (Acid binding capacity to a titration end point of pH 3) and ABC-4 (Acid binding capacity to a titration end point of pH 4) values in the diet indicating a reduction in the buffering capacity. For this reason, the gastric content of pigs on these diets would be expected to reach a low pH faster after feeding than in pigs fed non-acidified diets or diets with a normal Ca and/or P concentration. This is particularly beneficial in newly weaned pigs that produce insufficient levels of gastric HCl and, consequently, have a high pH in the stomach (Kidder and Manners, 1978). Obtaining low gastric pH is essential for the proper digestion of nutrients and in particular protein digestion (Kidder and Manners, 1978; Longland, 1991). In addition, a rapid drop in gastric pH after feeding can help prevent the establishment and multiplication of diarrhoea-causing micro-organisms (Bolduan *et al*., 1988).

Increases in feed intake in the early stages of Experiment 1 and tendencies towards increased feed intake in Experiment 3 along with increases in daily gain and improvements in feed conversion rate in Experiments 1 and 3 were observed as a result of including FA in the diet. The use of FA has previously been suggested as a means of lowering gastric acidity by supplementing natural HCl production and has been reported to improve growth performance (Giesting and Easter, 1985; Radecki *et al.,* 1988; Giesting, Roos and Easter, 1991; Lawlor *et al.,* 2005b). The benefits that arise from FA addition include an inhibitory effect on potentially pathogenic bacteria and their metabolites in the gastrointestinal tract (Blank *et al.,* 2001), increased amino acid and energy digestibilities (Mroz *et al.,* 1998; Blank *et al.,* 1999; Mroz *et al.,* 2000), increased digestibility of crude protein (Giesting and Easter, 1991) and an increase in nitrogen retention (Blank *et al.,* 2001). The growth promoting effect of FA depends on the extent to which feed intake is increased (Partanen, 2001). The diets in the present study were formulated predominantly from ingredients of vegetable origin and such 'simple' diets have shown higher and more consistent responses to FA inclusion than more ‘complex’ diets containing high levels of milk powder and fishmeal (Giesting and Easter, 1985; Easter, 1988; Giesting *et al.,* 1991).

Where feed intake and daily gain increases occurred in response to FA inclusion they occurred predominantly in the initial two weeks post weaning. This trend has been noted previously (Radecki *et al.*, 1988; Giesting *et al.*, 1991). The decline in response to FA with time post weaning may be due to the increasing maturity of the gastro-intestinal tract as pigs become accustomed to the solid diet (Weakland *et al.,* 1988).

Unlike in Experiments 1 and 3, there was no response FA in Experiment 2. This inconsistency seems to be a feature of studies with FA (Lawlor *et al*., 2005b). Partanen and Mroz (1999) in their review failed to find a satisfactory explanation for the effect of organic acids on feed intake. In the present study, the inconsistent response to FA may have been because of scouring in Experiments 1 and 3 where a response occurred. Pig health was excellent in Experiment 2 where no response was found to the use of FA. Tsiloyiannis *et al.* (2001) found that feed intake increased when FA was included in the diets of pigs challenged with *E. coli*. Owusu-Asiedu, Nyachoti and Marquardt (2003) also found that the shedding of *E. coli* and mortality levels were reduced when the diets of pigs challenged with K88 *E. coli* were supplemented with FA.

In agreement with the results of the present study, other studies have also found that calcium formate decreased feed intake and daily gain (Bohme, 1991; Pallauf and Huter, 1993; Reng *et al*., 1996; Overland *et al*., 2000). There is a danger when feeding calcium formate that unless other calcium sources in the diet are reduced appropriately, the high calcium concentration or calcium to phosphorus ratio will depress feed intake and daily gain (Pallauf and Huter, 1993). However, in the present study limestone flour was omitted from the calcium-formate supplemented diet to ensure that calcium concentration was similar to the control diet.

In the present study, calcium formate caused a one-unit drop in diet pH and, a slight increase in diet ABC-3. Contrary to this, other workers (Pallauf and Huter, 1993; Kirchgessner and Roth, 1990) found a reduction in ABC of diets when calcium formate was added. Bolduan *et al.* (1988) suggested that organic acids benefit pig performance because they lower dietary ABC. If lowering the ABC of a diet is the sole performance enhancing effect of calcium formate then the lack of response in the present study would not have been unexpected. Overland *et al*. (2000) cited this as a reason for the absence of an effect when a mixture of calcium and sodium formate was included in the diets of growing pigs. However, according to Kirchgessner and Roth (1989) improvements in pig performance due to calcium formate do not result solely from changes in pH and ABC of feed but also reflect the antimicrobial efficacy of the acid anion which is released under the acidic conditions of the stomach. It was also implied that the greatest response to calcium formate would be seen where animal health was compromised. While some animals in this study were treated for scour, there was no evidence of any beneficial effect from calcium formate and, in fact, it was found to depress feed intake and daily gain.

Omitting minerals from the diet caused the ABC-4 and ABC-3 of the experimental diets to decrease and consequently piglet performance tended to improve. Bolduan *et al.* (1988) suggested that a diet with a low ABC value would have an effect similar to that of organic acid supplementation. This was evident in week 1 of

Experiment 3 when feed intake increased in response to the addition of FA to the diet with a high level of Ca but not when it was added to diets with either normal or low levels of Ca.

The conflicting responses to the omission of limestone flour and dicalcium phosphate from the diet, between Experiments 1 and 2 may be explained by the difference in microbial challenge experienced by the pigs in the two experiments. A positive response was found in Experiment 1 when some scouring was noted but there was no response in Experiment 2 when pig health was excellent.

According to NRC (1998), pigs weighing 5 to 10 kg require dietary Ca and P concentrations of 8.0 and 6.5 g/kg, respectively. In Experiment 3, the low Ca diet did not meet the NRC Ca requirements. NRC (1998) also recommended a total Ca:P ratio of between 1:1 and 1.25:1 as optimum. Diets with high and low Ca levels in this experiment were well outside this range. Hall *et al.* (1985) and Reinhart and Mahan (1986) found that a high Ca: P ratio reduced P absorption, growth and bone calcification. The ratio was found to be most critical for diets marginal in P. The much lower Ca and P concentrations in the diet that were fed for one week post weaning in Experiment 1 increased feed intake and improved feed conversion rate.

Conclusion

Reducing the acid binding capacity of diets by FA addition or reducing Ca and/or P concentrations increased feed intake and growth rate to a similar degree. However, this response may be influenced by the health status of the pigs. There is a need for further research to examine the effect of enteric infection on the response to addition of FA and the omission of Ca and/or P from the diets of weanling pigs.

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