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Effect of creep feeding, dietary fumaric acid and level of dairy product in the diet on post-weaning pig performance

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Fumaric acid (FA), level of dairy product in the diet and creep feeding were evaluated in three experiments using individually fed pigs (weaned at *ca.* 21 days and weighing about 6 kg). They were assigned at random to treatments. In Experiment 1, the treatments were: (1) no pre-weaning creep and no FA post-weaning, (2) no pre-weaning creep and 20 g/kg FA post-weaning, (3) pre-weaning creep and no FA post-weaning, and (4) pre-weaning creep and 20 g/kg FA post-weaning. In Experiment 2, the treatments were: (1) 50 g/kg dried whey, (2) 50 g/kg whey with 20 g/kg FA, (3) 50 g/kg whey with 30 g/kg FA, (4) 200 g/kg whey, (5) 200 g/kg whey with 20 g/kg FA, (6) 200 g/kg whey with 30 g/kg FA. In Experiment 3, the treatments were: (1) high dairy product (whey plus skim milk powder) diet, (2) high dairy product diet with 20 g/kg FA, (3) low dairy product diet, (4) low dairy product diet with 20 g/kg FA. The number of pigs per treatment in Experiments 1, 2 and 3 was 16, 10 and 10, respectively. All diets contained barley, wheat, herring meal and full-fat soybean meal. In Experiment 1, FA inclusion increased intake (518 *v.* 466, s.e.d. 21.5 g/day, P < 0.05), daily gain (339 *v.* 280, s.e.d. 18.1 g/day, P < 0.01) and improved feed conversion rate (1.55 *v.* 1.70, s.e.d. 0.06, P < 0.05) in the first 3 weeks post-weaning. In Experiment 2, there was no effect of treatment. In Experiment 3, increasing the level of dairy product in the diet increased feed intake (P = 0.06) and daily gain (P < 0.05) and improved feed conversion rate (P < 0.01). The conclusions are that FA improved post-weaning performance and that increasing the level of dairy products in postweaning diets also improved performance.

Keywords: Dairy product; dried whey; fumaric acid; pig post-weaning

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Introduction

Early weaned pigs may produce insufficient levels of gastric HCl, which can result in a high pH in the stomach chyme (Kidder and Manners, 1978). As a result, the digestion of nutrients, especially protein, is reduced (Kidder and Manners, 1978; Longland, 1991). In addition, conditions of high pH are favourable for the establishment and multiplication of diarrhoea-causing micro-organisms (Bolduan *et al*., 1988). The use of fumaric acid (FA) has been suggested as a means of lowering gastric acidity by supplementing natural HCl production and has been reported to improve growth performance (Kirchgessner and Roth, 1976; 1982; Falkowski and Aherne, 1984; Giesting and Easter, 1985; Radecki, Juhl and Miller, 1988; Giesting, Roos and Easter, 1991). The benefits from feeding FA 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).

Creep feeding of suckling pigs is thought to benefit post-weaning pig performance by stimulating HCl production (Cranwell, Noakes and Hill, 1976) and enzyme secretory capacity (Aumaitre, 1972; English, Robb and Dias, 1980; Shields, Ekstrom and Mahan, 1980; Sloat, Mahan and Roehrig, 1985; Seve, 1985) prior to weaning.

The response to FA is greatest in diets with low levels of dairy products (Giesting *et al.*, 1991). Dairy products contain lactose which can be fermented to lactic acid thus reducing gut pH (Kidder and Manners, 1978; Easter, 1988). In addition, milk proteins are much more easily digested in the immature gut than vegetable proteins (Walker *et al.*, 1986).

The objective of Experiment 1 was to assess the effect of FA inclusion in the diet on growth performance of weaned pigs which did or did not have access to creep feed pre-weaning. The objective of Experiment 2 was to assess the effect of FA level in diets with a high or low dried whey content. The objective of Experiment 3 was to determine the effect of FA in diets with high or low levels of dried whey and skim milk powder.

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 content and chemical analysis of the experimental diets are presented in Table 1.

Experiment 1

Experiment 1 was designed as a split-plot with creep feeding as the main plot and FA as the sub-plot. Litters of pigs were selected at 4 days of age and randomly allocated to either creep feeding (low-whey diet without FA; Diet 1) or no creep feeding to weaning at 19 to 23 days of age. At weaning, 64 pigs (32 males and 32 females) were weighed individually, paired on pre-weaning treatment, sex and weight and allocated at random from within pairs to the following two treatments for 23 days: (1) low-whey diet without FA (Diet 1) and (2) low-whey diet with 20 g/kg FA (Diet 2). Pigs were weighed at the end of the experimental period.

Experiment 2

Sixty pigs (30 males and 30 females) were weaned at 18 to 22 days of age, weighed individually and blocked on the basis of sex and weight. Two levels of whey and three levels of FA were used in a 2 × 3

Table 1. Ingredient composition and chemical analysis of experimental diets

Item	Diet									
	1	2	3	4	5	6	7	8	9	10
Ingredient (g/kg)										
Barley	160	160	160	160	160	160	100	100	160	160
Wheat	458.5	438.5	428.5	367.5	347.5	337.5	303	283	438	418
Dried whey	50	50	50	200	200	200	150	150	50	50
Dried skim	–	–	–	–	–	–	100	100	–	–
Herring meal	50	50	50	100	100	100	100	100	50	50
Soya full fat	125	125	125	125	125	125	175	175	125	125
Soyabean meal	100	100	100	–	–	–	–	–	120	120
Soya oil	20	20	20	20	20	20	50	50	20	20
L-Lysine	2	2	2	1	1	1	1.5	1.5	2	2
DL-Methionine	1	1	1	0.5	0.5	0.5	1.5	1.5	1	1
L-Threonine	1.5	1.5	1.5	1	1	1	1.5	1.5	1.5	1.5
Di-calcium phosphate	10	10	10	5	5	5	3	3	12	12
Limestone flour	12	12	12	10	10	10	6	6	9	9
Salt	2.5	2.5	2.5	2.5	2.5	2.5	1	1	4	4
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	30	–	20	30	–	20	–	20
Chemical analysis (g/kg)										
Dry matter	875	879	878	886	887	887	916	916	891	893
Ash	56.5	57.7	56.0	62.0	60.1	59.4	56.3	55.1	58.3	57.8
Fat	64.5	64.0	63.5	66.0	65.5	63.5	100.5	100.5	67.5	66.0
Fibre	35.0	33.4	31.9	30.0	30.8	25.7	25.0	25.1	32.9	32.0
Protein	220.0	215.0	214.0	213.0	208.0	206.0	224.0	220.0	212.0	207.0
Digestible energy (MJ/kg)	14.5	14.4	14.4	14.7	14.6	14.6	15.8	15.8	14.5	14.4
Lysine	12.8	12.7	12.7	13.0	12.9	12.9	16.4	16.4	12.8	12.8

Table 1. (continued)

Item	Diet									
	1	2	3	4	5	6	7	8	9	10
Diet acidity										
Diet pH	6.11	4.90	4.40	7.09	4.60	4.15	6.85	5.00	6.50	5.00
ABC[4]-4 (mEq HCl/kg)	354	230	112	360	222	60	360	240	320	210
ABC[4]-3 (mEq HCl/kg)	684	600	496	710	624	6 00	690	630	630	500

[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, 4 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]75 g oxytetracycline and 25 g spiramycin per kg.
[3]Product of Kemin Industries Inc, Des Moines, Iowa, USA.
[4]Acid binding capacity (Lawlor *et al.*, 2005).

factorial arrangement of treatments. One pig from each block was assigned at random to each of the following treatments for 26 days: (1) low-whey diet without FA (Diet 1), (2) low-whey diet with 20 g/kg FA (Diet 2), (3) low-whey diet with 30 g/kg FA (Diet 3), (4) high-whey diet without FA (Diet 4), (5) high-whey diet with 20 g/kg FA (Diet 5), and (6) high-whey diet with 30 g/kg FA (Diet 6). Pigs were weighed after 14 days on trial and at the end of the experiment.

Experiment 3

Fifty pigs (25 male and 25 female) were weaned at 21 to 24 days of age, blocked on sex and weight and assigned at random from within blocks to four dietary treatments for 26 days as follows: (1) high-dairy-product diet (Diet 7), (2) high-dairy-product diet with 20 g/kg FA (Diet 8), (3) low-dairy-product diet (Diet 9), (4) low-dairy-product diet with 20 g/kg FA (Diet 10).

Housing

Pigs were accommodated 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/day.

Feeding

Pigs were offered feed *ad libitum* with care taken to avoid wastage and intake was recorded. Feeding was from a stainless steel trough (0.6 m long). Water was available *ad libitum* from nipple drinkers (one per pig). Pigs in Experiments 2 and 3 were offered Diet 1 and Diet 7, respectively, in the farrowing house from 10 days of age. The 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 21 to 23 days of age.

Management

Pigs were observed closely at feeding time. Any pig showing signs of ill-health was treated as appropriate. Feeders and drinkers were checked daily and cleaned or adjusted as required.

Feed manufacture

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.

Feed analysis

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

Statistical analysis

In all three experiments, the pig was considered to be the experimental unit. Data from Experiment 1 were subjected to analysis of variance using GENSTAT (Genstat, 1993) for a split-plot design. The model had terms for creep feed, level of FA and their interaction.

Data from Experiment 2 were analysed using the general linear model procedure of SAS (SAS, 1996) for a randomised complete block design with treatments (level of whey and level of FA) arranged as a 2 × 3 factorial. The model used had terms for block, level of whey, level of FA and the interaction of whey × FA level.

Data from Experiment 3 were subjected to analysis of variance using GENSTAT (Genstat, 1993) for a randomised complete block with treatments (level of dairy product and level of FA) arranged as a 2 × 2 factorial. The model used had terms for block, level of dairy product, level of FA and the interaction of dairy product × FA level.

Results

Experiment 1

In the first week, one pig from each treatment was treated for scour. One of these (Diet 1) died and the other (Diet 2) was removed due to failure to eat. During week 2, one pig was removed from Diet 2 because of failure to thrive. One pig, also from Diet 2, died during the third week.

There was no significant creep feed × FA interaction for pig performance (Table 2), but there was a tendency ($P = 0.13$) for feed intake in the first week post-weaning to be higher for FA when pigs had received creep feed prior to weaning. There was also a tendency ($P = 0.09$) for a similar interaction effect for feed conversion rate.

Feed intake was increased by including FA in the diet both in the first week ($P < 0.001$) and for the overall period ($P < 0.05$). There was also a tendency for feed intake to increase in response to FA in weeks 2 ($P = 0.11$) and 3 ($P = 0.13$). Daily gain increased from 280 to 339 g/day (s.e.d. 18; $P < 0.01$) and feed conversion rate improved from 1.70 to 1.55 g/g (s.e.d. 0.059; $P < 0.05$) in response to FA inclusion in the diet.

Experiment 2

In the first 2 weeks, two pigs (Treatments 1 and 5) died and five (Treatment 6, 1, 1, 4 and 5) were removed due to failure to eat. Scouring was noted in some pigs on all treatments at this time.

There was no effect of any of the levels of FA on pig performance. Neither was

Table 2. Effect of pre-weaning creep feeding on response of weaned pigs to fumaric acid (FA) in the diet (Experiment 1)

	Treatment[1]				s.e.d.	F-test for FA[2]
	No creep		Creep			
	No FA	FA	No FA	FA		
No. of pigs	16	16	16	16		
Weaning age (days)	21.4	21.5	21.4	21.7	0.20	
Pig weight (kg)						
Weaning	6.1	6.1	6.2	6.0	0.31	
Final	12.1	12.9	11.9	13.6	0.67	**
Feed intake (g/day)						
Week 1	194	233	180	260	19.0	***
Week 2	528	550	533	623	46.0	
Week 3	658	696	667	711	43.7	
Overall	466	500	466	535	30.3	*
Daily gain (g/day)						
Overall	289	320	273	358	23.6	**
Feed conversion rate (g/g)						
Overall	1.64	1.60	1.75	1.50	0.080	*

[1]See Table 1 for dietary composition.
[2]FA inclusion at 20 g/kg; there was no effect of creep and no interaction between creep and FA inclusion.

there any effect of whey level or any FA × whey interaction.

Experiment 3

Two pigs were removed due to their failure to thrive, one from Treatment 1 and one from Treatment 3. Both pigs had been treated for scour as was one pig on Treatment 2.

There was no FA × dairy product level interaction for feed intake, daily gain, feed conversion rate, or pig weight. Neither were these performance measures affected by the level of FA in the diet. However, feeding a high level of dairy product increased feed intake during weeks 1 and 2 from 283 to 321 g/day (s.e.d. 19.6; $P = 0.06$), overall daily gain from 339 to 395 g/day (s.e.d. 26.4, $P < 0.05$) and final pig weight from 15.4 to 16.8 kg (s.e.d. 0.71, $P < 0.05$). Overall feed conversion rate was improved from 1.46 to 1.32 g/g (s.e.d. 0.051, $P < 0.01$) when the level of dairy product in the diet was increased.

Discussion

Response to FA inclusion

In Experiment 1, the feed intake increase in response to FA inclusion in the diet agrees with some reports in the literature (Hoppenbrock, 1979; Kirchgessner and Roth, 1982; Falkowski and Aherne, 1984; Giesting *et al.,* 1991). Increased feed intake in response to diet acidification may be due to improved health as some experiments have found a reduction in diarrhoea from the use of organic acids (Partanen, 2001; Tsiloyiannis *et al.,* 2001). However, in Experiments 2 and 3, no significant response in intake was obtained from including FA in the diet. This was in

Table 3. Effect of whey and fumaric acid (FA) in the diet on pig performance (Experiment 2)

	Treatment[1]						s.e.[2]
	Low whey			High whey			
	FA-0	FA-20	FA-30	FA-0	FA-20	FA-30	
No. of pigs	10	10	10	10	10	10	
Weaning age	21.6	21.7	21.8	21.8	21.9	21.9	
Pig weight (kg)							
Weaning	5.9	6.0	6.0	5.9	5.8	6.0	0.14
Day 14	8.0	8.6	8.4	8.3	8.4	8.3	0.28
Final	15.6	16.1	16.0	16.1	15.6	15.8	0.56
Feed intake (g/day)							
Weeks 1 to 2	243	276	271	286	267	268	19.8
Weeks 3 to 4	771	756	742	791	749	763	36.8
Overall	517	525	515	548	517	524	26.9
Daily gain (g/day)							
Weeks 1 to 2	165	201	185	185	194	181	19.8
Weeks 3 to 4	546	534	540	556	516	539	35.5
Overall	363	374	369	377	361	367	22.6
Feed conversion rate (g/g)							
Weeks 1 to 2	1.52	1.40	1.51	1.57	1.41	1.51	0.099
Weeks 3 to 4	1.42	1.47	1.38	1.43	1.46	1.42	0.071
Overall	1.43	1.44	1.40	1.46	1.44	1.44	0.056

[1]Low whey = 50 g/kg; high whey = 200 g/kg; FA-0 = No FA; FA-20 = 20 g FA per kg; FA-30 = 30 g FA per kg.
[2]There were no significant effects of whey level or FA inclusion and no interaction.

line with the majority of findings which show that intake was either unchanged or slightly reduced when acidification using FA was carried out (Kirchgessner and Roth, 1976; Henry, Pickard and Hughes, 1985; Radecki *et al.,* 1988; Risley *et al.,* 1991; Weakland, Risley and Kornegay, 1988; Giesting and Easter, 1985).

There is no obvious explanation for why the effect of FA on intake differed between experiments in this study and between studies elsewhere. It may be that pigs in Experiment 1 suffered a higher microbial challenge than pigs in Experiments 2 or 3. Tsiloyiannis *et al.* (2001) found that intake was increased when FA was added to diets of pigs that had been challenged with *E. coli*. Owusu-Asiedu, Nyachoti and Marquardt (2003) also found that the shedding of *E. coli* and mortality level were reduced when pigs challenged with the K88 *E. coli* strain were fed a diet with 20 g/kg FA. Scouring was observed in all of the present experiments, but only in Experiment 1 did feed intake and growth respond to supplementation with FA. Most of the studies reported in the literature (as was the case here) used individually-housed pigs where the risk of diarrhoea would have been smaller than under commercial conditions. Partanen (2001) analysed the response to FA in 18 published experiments and found it had no overall effect on feed intake. Partanen and Mroz (1999) in their review failed to find a satisfactory explanation for the inconsistent effect of organic acids on feed intake.

Table 4. Performance of pigs fed high or low dairy product diets with or without fumaric acid suplementation (Experiment 3)

	Treatment[1]				s.e.d.	F-test[2] for dairy product
	Low dairy product		High dairy product			
	FA-0	FA-20	FA-0	FA-20		
No. of pigs	10	10	10	10		
Weaning age (days)	20.5	20.6	20.9	21.0	0.24	
Pig weight (kg)						
Weaning	6.2	6.2	6.1	6.2	0.07	
Final	15.0	15.8	16.4	17.2	0.99	*
Feed intake (g/day)						
Weeks 1 to 2	281	285	316	327	27.7	P=0.06
Weeks 3 to 4	662	715	703	741	57.2	
Overall	465	492	503	526	39.5	
Daily gain (g/day)						
Overall	324	353	384	407	37.3	*
Feed conversion rate (g/g)						
Overall	1.49	1.42	1.32	1.32	0.072	**

[1]Low dairy product = whey only (50 g/kg); High dairy product = dried skim milk (100 g/kg) plus whey (50 g/kg); FA-0 = No Fa, FA-20 = 20 g FA per kg.
[2]There was no significant effect of FA inclusion and no interaction with level of dairy product.

Improvements in both daily gain and feed conversion rate from FA supplementation were also observed in Experiment 1. This was not surprising since the growth promoting effect of organic acids depends on the extent to which they increase feed intake (Partanen, 2001). Other workers also showed improvements in performance due to FA (Giesting and Easter, 1985; Kirchgessner and Roth, 1976, 1982; Falkowski and Aherne, 1984; Radecki *et al.,* 1988; Giesting *et al.,* 1991), with higher responses on diets of vegetable origin than on complex diets containing high levels of milk powders and fish meal (Giesting and Easter, 1985; Easter, 1988; Giesting *et al.,* 1991). This is why dried whey was limited to 50 g/kg in the diets in Experiment 1. The absence of a response to FA inclusion in diets of high or low dairy-product content in Experiments 2 and 3 is consistent with the findings of several other studies (Henry *et al.*, 1985; Edmonds, Izquierdo and Baker, 1985; Risley *et al.,* 1991).

The inclusion of FA in the low dairy-product diet used in Experiment 1 resulted in an improvement in feed conversion rate. Radecki *et al.* (1988) and Giesting *et al.* (1991) found that the greatest increase in daily gain and in feed conversion rate in response to FA was for a short period (1 to 2 weeks) immediately post-weaning. However, no such response was found in Experiment 2 of the present study. In Experiment 3, pigs were weighed only at weaning and again 4 weeks later. This 4-week period may have been too long to detect a response which may only have lasted for 1 or 2 weeks. The decline in response to FA with time post-weaning may be due to the increasing maturity of the gastrointestinal tract as pigs become accustomed to the solid diet (Weakland *et al.,* 1988).

Response to creep feeding

The practice of creep feeding has been reported to help initiate and increase HCl secretion in the piglet stomach (Cranwell *et al.,* 1976; Cranwell and Moughan, 1989) and to stimulate the production of digestive enzymes (Aumaitre, 1972; English *et al.,* 1980; Sloat *et al.,* 1985). In Experiment 1, where creep feeding had no effect on feed intake or growth performance, it had been expected that pigs which had received creep would show the least response to FA because HCl secretory capacity in such pigs would have been improved by creep feeding. However, it has been suggested that creep feeding provides little advantage for pigs in the first 3 weeks of life (as was the case here) due to low and variable feed intake at this time (Pluske, Williams and Aherne, 1995; Kavanagh, 1995; Koketsu and Dial, 1998).

Effect of level of dairy product in the post-weaning diet

Complex diets that contain dried milk powder and fishmeal products are often used to alleviate the effects of the sudden change from sows' milk to solid feed at weaning (Bayley and Carlson, 1970). The milk components in the diet help to maintain villous height in the small intestine, increase absorption and thus increase growth rate (Zijlstra *et al.,* 1996). In Experiment 2, no difference in feed intake, daily gain or feed conversion rate was observed between diets with high and low dried-whey contents. This finding is not in agreement with earlier findings that daily gain and feed conversion rate were improved as the proportion of milk protein in the starter diet increased (Himmelberg *et al.,* 1985; Bayley and Carlson, 1970). However, in Experiment 3 the high-dairy-product diet contained higher levels of dairy product and fishmeal than in Experiment 2 and this may have been responsible for the increases in intake, daily gain and final weight and the improvement in feed conversion rate.

With regard to diet type, most work suggests that pigs fed a simple diet show a greater response to FA use and to increasing FA level than pigs fed a complex diet (Giesting and Easter, 1985; Easter, 1988; Giesting *et al.,* 1991). The lactose from milk products is converted to lactic acid in the stomach increasing gastric acidity and thus is thought to reduce the efficacy of diet acidification (Easter, 1988). However, no such interaction was found in the present study as there was no response to FA in Experiments 2 or 3.

Conclusion

Creep feed prior to weaning had no effect on post-weaning performance and did not affect the post-weaning response to FA. Feed intake, daily gain and feed conversion rate improved when high levels of dried whey and skim milk powder were fed in post-weaning diets but diet composition did not affect the response to FA. There appears to be unidentified factors such as the level of microbial challenge that affect the response of pigs to FA.

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