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Interaction between lactose levels and antimicrobial growth promoters on growth performance of weanling pigs

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Abstract: In experiment 1, 224 pigs (initially 8.85 kg and 28 ±2 days of age) were used in a 2 × 2 factorial arrangement of treatments to investigate the interaction between lactofeed (LF70) (860 g kg^{-1} whey permeate, 140 g kg^{-1} soya bean meal) level (175 g kg^{-1} and 350 g kg^{-1}) and avilamycin (0 and 40 mg kg^{-1}) inclusion in piglet starter diets. Pigs were fed starter diets from day 0 to day 22 and a transition diet was fed from day 23 to day 39. The inclusion level of LF70 in the transition diet was 75 g kg^{-1} and 150 g kg^{-1}. Pigs fed 350 g kg^{-1} LF70 had a higher daily gain (ADG) ($p < 0.01$) and an improved feed conversion ratio (FCR) ($p < 0.05$) during the starter period than the pigs fed 175 g kg^{-1} LF70. Pigs fed medicated diets had a higher ADG ($p < 0.05$) and an improved FCR ($p < 0.05$) than the non-medicated fed pigs during the starter period. There was an increase in feed intake (AFI) ($p < 0.05$) during the transition period with increasing levels of LF70. There was an improvement in FCR during the transition period with the inclusion of avilamycin ($p < 0.01$). There was a significant interaction ($p < 0.01$) between LF70 and avilamycin for ADG during the transition period. The inclusion of avilamycin at 175 g kg^{-1} LF70 inclusion had no effect ($p > 0.05$) on ADG. However at 350 g kg^{-1} LF70 inclusion the pigs offered medicated diets had a higher ADG ($p < 0.001$) compared with non-medicated diets. In experiment 2, 224 pigs (initially 8.85 kg and 28 ±2 days of age) were used in a 2 × 2 factorial to investigate the interaction between LF70 level (175 g kg^{-1} and 350 g kg^{-1}) and zinc oxide (ZnO) (0 and 3.1 g kg^{-1}) inclusion in piglet starter diets. The inclusion level of LF70 in the transition diet was 75 g kg^{-1} and 150 g kg^{-1} and of ZnO was 2 g kg^{-1}. There was a significant increase ($p < 0.05$) in ADG with increasing levels of LF70 during the starter period. The inclusion of ZnO during the starter period resulted in an increase in ADG ($p < 0.001$) and FCR ($p < 0.05$) compared with no ZnO inclusion. Neither the inclusion of zinc oxide not of LF70 had an effect ($p > 0.05$) on performance during the transition period. In conclusion the supplementation of starter diets with increasing levels of LF70, ZnO and avilamycin resulted in increased ADG and improved FCR.

Keywords: pigs; lactose; antibiotics; zinc oxide

INTRODUCTION

In recent times there has been a considerable intensification of the livestock industry with greater growth rate, stocking density and larger production units.[1] The increased pressure on production has resulted in an increase in the use of antimicrobial growth promoters to improve performance and (or) health.[1] The primary effects associated with the inclusion of antimicrobial feed additives include the prevention of digestive disturbances, improved feed utilisation and animal performance.[2] Antibiotics are commonly used as feed growth promoters as well as being used at higher levels for therapeutic purposes.[1] However recommendations by the Swann report[3] requested more strict government control on the use of antibiotics in feed. This report concluded that the administration of antibiotics to farm livestock, particularly at sub-therapeutic levels, poses certain hazards to human and animal health; in particular it had led to resistance in enteric bacteria of animal origin.

Zinc oxide has also been shown to have growth promoting effects when fed in pharmacological doses.[4–6] The inclusion of 3.0 g of zinc kg^{-1} has been shown to increase weight gains by 17% and daily feed intake by 14%.[4] The incidence and severity of diarrhoea can also be reduced by the inclusion of pharmacological doses of zinc in starter diets.[7] However, the use of zinc results in large amounts of the nutrient in pig manure which is spread on fields as fertilizer. When zinc builds up faster than crops can use it, nutrient pollution and water quality become a concern.[8]

Many authors have noted the improved performance when whey is added to weanling pig diets.[9–12] The improved gain and feed intake when whey is added

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is primarily due to the lactose component and secondarily from the contribution of supplemented amino acids.[13] Lactose is readily fermented by the weanling pig to lactic acid owing to the presence of *Lactobacilli*.[14] The resultant lower pH in the stomach increases both gastric proteolysis and nutrient digestibility.[14] The increased production of lactic acid can delay the multiplication of pathogenic bacteria, thereby improving gastrointestinal health.[15] The improved gastrointestinal health results in enhanced growth performance and an improved feed efficiency.[2] It is our hypothesis that high dietary concentrations of lactose could be used to promote growth and as a possible replacement for antimicrobial growth promoters and zinc. The objective of this experiment is to compare two levels of lactofeed (860 g kg^{-1} whey permeate, 140 g kg^{-1} soya bean meal) with avilamycin (antimicrobial growth promoter) and zinc oxide on pig performance and diet digestibility postweaning.

MATERIALS AND METHODS

Animals

Two experiments were conducted to examine the interaction between lactofeed level and avilamycin or zinc oxide. Both experiments were carried out over two experimental runs. Two hundred and twenty-four Large White × (Large White × Landrace) pigs were used in each experiment, after weaning at 28 days of age (initial mean live weight of 8.85 kg). In experiment 1 the pigs in run 1 and run 2 had an initial mean live weight of 9.2 kg and 8.1 kg respectively. In experiment 2 the pigs in run 1 and run 2 had an initial mean live weight of 9.2 kg and 8.2 kg respectively.

Experiment 1: diets

A 2 × 2 factorial arrangement was used to evaluate the response of weanling pigs to two levels of lactofeed with and without avilamycin. The pigs were blocked on the basis of weight and sex, and assigned to one of four dietary treatments (56 animals on each treatment, 8 replicate pens containing 7 pigs in each) in a complete randomised block design. The starter diet (Table 1) was fed for 22 days post-weaning and a transition diet was fed for the remaining 17 days. The pigs were offered the following starter diets in meal form: (T1) 175 g kg^{-1} lactofeed and no avilamycin, (T2) 175 g kg^{-1} lactofeed and 40 ppm of avilamycin (Maxus, Elanco Animal Health), (T3) 350 g kg^{-1} lactofeed and no avilamycin and (T4) 350 g kg^{-1} lactofeed and 40 ppm of avilamycin. The pigs were offered the following transition diets (Table 2) in meal form: (T1) 87.5 g kg^{-1} lactofeed and no avilamycin, (T2) 87.5 g kg^{-1} lactofeed and 40 ppm of avilamycin, (T3) 175 g kg^{-1} lactofeed and no avilamycin and (T4) 175 g kg^{-1} lactofeed and 40 ppm of avilamycin.

Experiment 2: diets

A 2 × 2 factorial arrangement was used to evaluate the response of weanling pigs to two levels of lactofeed with and without zinc oxide. The pigs were blocked on the basis of weight and sex, and assigned to one of four dietary treatments (56 animals on each treatment, 8 replicate pens containing 7 pigs in each). The starter diet (Table 1) was fed for 22 days post-weaning and a transition diet was fed for the remaining 17 days. The pigs were offered the following starter diets in meal form: (TT1) 175 g kg^{-1} lactofeed and no zinc oxide, (TT2) 175 g kg^{-1} lactofeed and 3.1 g of zinc oxide kg^{-1}, (TT3) 350 g kg^{-1} lactofeed and no zinc oxide and (TT4) 350 g kg^{-1} lactofeed and 3.1 g of zinc oxide kg^{-1}. The pigs were offered the following transition diets (Table 2) in meal form: (TT1) 87.5 g kg^{-1} lactofeed and no zinc oxide, (TT2) 87.5 g kg^{-1} lactofeed and 2.0 g of zinc oxide kg^{-1}, (TT3) 175 g kg^{-1} lactofeed and no zinc oxide and (TT4) 175 g kg^{-1} lactofeed and 2.0 g of zinc oxide kg^{-1}.

Chromic oxide was added to all diets at the time of compounding at 120 mg kg^{-1}. In both experiments, lactofeed was added at the expense of maize. All diets were isocalorific, formulated to an estimated digestible energy (DE) content (starter 16.2 MJ kg^{-1}, transition 15.1 MJ kg^{-1}). Diets were formulated to contain 16 g kg^{-1} of total lysine in the starter diets and 15 g kg^{-1} in the transition). Levels of threonine, sulfur amino acids (methionine + cysteine), and tryptophan were maintained at 65, 55 and 18% of lysine respectively to satisfy the ideal protein requirement[16] through the addition of synthetic amino acids (Tables 1 and 2).

Management

The pigs were fed *ad libitum* with care taken to avoid wastage. Water was available *ad libitum* from nipple drinkers. Pigs were housed in flat decks in group sizes of seven in fully slatted pens. Temperature was maintained at 30 °C in the first week and reduced by 2 °C per week to 22 °C in week 5. Pigs were weighed at the beginning of the experiment, on day 8, day 16, day 22, day 29 and day 39. Feed was available up to weighing. Throughout the experiment representative samples of the starter and transition diets were taken at the time of feeding and retained for chemical analysis. Samples of faeces were collected by rectal palpation for chromium analysis from three pigs per pen during the starter period (from day 18 to 22 inclusive) and during the transition period (from day 31 to 34 inclusive). The same three pigs were sampled on all occasions and equal amounts of excreta samples were mixed and pooled for each pen at the end of the collection period. All pens were sampled.

Laboratory analysis

In experiments 1 and 2 the diets and faeces were analysed for nitrogen, dry matter, ash, gross energy, neutral detergent fibre (NDF) and chromium concentration. The diets were also analyzed for crude fibre and ether extract concentration. After collection the faeces were dried at 100 °C for 48 h. The concentrates and dried faeces were milled through a 1-mm screen (Christy and Norris hammer mill, lpswich, UK). Ash was

Table 1. Composition and analysis of the experimental starter diets (g kg^{-1})

Treatment, expt 1	T1	T2		T3	T4	
Treatment, expt 2	TT1		TT2	TT3		TT4
Composition (*g kg*$^{-1}$)						
Lactofeed[a]	175	175	175	350	350	350
Extruded wheat	138.8	138.6	135.7	139	138.8	135.9
Extruded maize	225	225	225	50	50	50
Full fat soya	140	140	140	140	140	140
Skim milk	100	100	100	100	100	100
Soya bean meal	76	76	76	76	76	76
Fish meal	75	75	75	75	75	75
Soya oil	55	55	55	55	55	55
Minerals and vitamins[b]	10	10	10	10	10	10
Avilamycin[c]		+			+	
Zinc oxide			3.1			3.1
Synthetic amino acids						
Lysine HCl	2.5	2.5	2.5	2.5	2.5	2.5
Methionine	1.5	1.5	1.5	1.5	1.5	1.5
Threonine	1.0	1.0	1.0	0.8	0.8	0.8
Tryptophan	0.2	0.2	0.2	0.2	0.2	0.2
Analysis (*g kg*$^{-1}$)						
Dry matter	876.7	887.2	884.9	891.0	898.8	909.2
Ether extract	101.0	98.2	98.3	78.3	87.5	78.9
Crude protein	226.3	227.1	225.2	227.7	221.4	231.0
Crude fibre	33.9	29.3	31.3	26.0	31.0	27.3
Neutral detergent fibre	119.8	133.4	123.7	107.6	116.4	126.2
Crude ash	51.9	57.0	60.4	69.1	66.8	70.6
Gross energy (MJ kg^{-1})	16.81	17.65	17.65	17.32	17.01	17.07
Lysine[d]	16.1	16.1	16.1	16.4	16.4	16.4
Methionine and cysteine[d]	8.8	8.8	8.8	8.6	8.6	8.6
Threonine[d]	8.7	8.7	8.7	8.7	8.7	8.7
Tryptophan[d]	2.6	2.6	2.6	2.7	2.7	2.7
Zinc (ppm)			2396.5			2451.0

[a] The Lactofeed was manufactured by Volac International Ltd, Orwell, Royson, Herts, SG8 5QX, United Kingdom. The chemical analysis is as follows (g kg^{-1} unless otherwise stated): dry matter 955, crude protein 125, oil 50, ash 90, fibre 10, gross energy content of 15.5 MJ kg^{-1} and a pH of 6.5–7.
[b] 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; endox, 60 mg. Chromic oxide included at 120 mg per kilogram of complete diet.
[c] Diets T2 and T4 contained 200 mg kg^{-1} avilamycin (Elanco Animal Health) which provided 40 mg avilamycin per kg of finished feed.
[d] Calculated from proximate analyses (Ministry of Agriculture, Fisheries and Food, 1991).

determined after ignition of a known weight of feed or faeces in a muffle furnace (Nabertherm, Bremen, Germany) at 550 °C for 4 h. Crude protein was determined as Kjeldahl N × 6.25 using a Buchi 435 digestion unit and a Buchi 323 distillation unit (Buchi, Postfach, Flawil/Schweiz, Switzerland) according to AOAC.[17] NDF and crude fibre were determined using a Fibertec extraction unit (Tecator, Hoganans, Sweden). The NDF was determined according to the method of Van Soest *et al*[18] and the crude fibre was determined by the Weende method.[17] The gross energy of both feed and faecal samples were determined using a Parr 1201 oxygen bomb calorimeter (Parr, Moline Illinois, USA). Diethyl ether extract was determined using the 1043 Soxtec System as derived from the Soxhlet method. The chromium concentration was determined according to the method of Williams *et al*.[19]

Statistical analysis

The data of both experiments were analysed using the general linear model procedure of the SAS.[20] The model used in experiment 1 included the effects of lactofeed level, avilamycin inclusion, run, initial block and associated two-way interactions and three-way interactions. The model used in experiment 2 included the effects of lactofeed level, zinc oxide inclusion, run, initial block and associated two-way interactions and three-way interactions. The data are presented as least square means (LSM) ± standard error of the means (SEM).

RESULTS

Experiment 1

Pig performance

The effect of lactofeed and avilamycin on average daily gain (ADG), feed intake and food conversion ratio (FCR) during the starter, transition and during the combined starter-transition period is shown in Table 3.

There was a significant interaction ($p < 0.05$) between lactofeed and avilamycin for ADG from day

Table 2. Composition and chemical analysis of experimental transition diets (g kg^{-1})

Treatment, expt 1	T1	T2		T3	T4	
Treatment, expt 2	TT1		TT2	TT3		TT4
Composition (g kg^{-1})						
Lactofeed[a]	87.5	87.5	87.5	175	175	175
Wheat	214.0	213.8	212	314.1	313.9	312.1
Maize	200	200	200	131	131	131
Extruded wheat	118.5	118.5	118.5	0	0	0
Full fat soya	120	120	120	120	120	120
Soya bean meal	150	150	150	150	150	150
Fish meal	60	60	60	60	60	60
Soya oil	35	35	35	35	35	35
Mineral and vitamins[b]	10	10	10	10	10	10
Avilamycin[c]		+			+	
Zinc oxide			2			2
Synthetic amino acids						
Lysine HCl	2.5	2.5	2.5	2.5	2.5	2.5
Methionine	1.5	1.5	1.5	1.5	1.5	1.5
Threonine	0.9	0.9	0.9	0.8	0.8	0.8
Tryptophan	0.1	0.1	0.1	0.1	0.1	0.1
Analysis (g kg^{-1})						
Dry matter	873.8	874.0	873.3	867.2	866.1	867.6
Crude oil	75.2	76.0	72.8	65.2	72.4	68.8
Crude protein	199.9	201.1	210.0	199.7	201.5	209.1
Crude fibre	40.7	35.3	31.8	36.2	28.0	32.5
Neutral detergent fibre	116.5	144.4	136.1	106.8	116.6	126.1
Crude ash	43.3	47.4	50.3	49.6	53.3	54.9
Gross energy (MJ kg^{-1})	17.11	16.95	17.05	17.06	16.82	16.97
Lysine[d]	14.5	14.5	14.5	14.6	14.6	14.6
Methionine and Cysteine[d]	8.4	8.4	8.4	8.3	8.3	8.3
Threonine[d]	8	8	8	8	8	8
Tryptophan[d]	2.7	2.7	2.7	2.7	2.7	2.7
Zinc			1622.5			1813.0

[a] The Lactofeed was manufactured by Volac International Ltd, Orwell, Royston, Herts, SG8 5QX, United Kingdom. The chemical analysis is as follows (g kg^{-1} unless otherwise stated): dry matter 955, crude protein 125, oil 50, ash 90, fibre 10, gross energy content of 15.5 MJ kg^{-1} and a pH of 6.5–7.
[b] 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; endox, 60 mg. Chromic oxide included at 120 mg per kilogram of complete diet.
[c] Diets T2 and T4 contained 200 mg kg^{-1} avilamycin (Elanco Animal Health) which provided 40 mg avilamycin per kg of finished feed.
[d] Calculated from proximate analyses (Ministry of Agriculture, Fisheries and Food, 1991).

0 to 8 and feed conversion ratio (FCR) from day 8 to 16. The pigs offered diets containing avilamycin at the low level of lactofeed had a higher ADG from day 0 to 8 than pigs offered diets containing no avilamycin. However the inclusion of avilamycin had no significant effect at the high inclusion of lactofeed. The inclusion of avilamycin at the low level of lactofeed had no significant effect on FCR ($p > 0.05$) from day 8 to 16. However at the high inclusion of lactofeed the pigs offered diets containing avilamycin had a significantly improved FCR compared with pigs offered diets containing no avilamycin. The pigs offered diets containing the high inclusion of lactofeed had a higher ADG ($p < 0.05$) between days 8 to 16, 16 to 22 and during the overall starter period ($p < 0.01$) and a significantly improved FCR ($p < 0.05$) during the starter period compared with pigs offered diets containing the low level of lactofeed.

The pigs offered diets containing avilamycin had a significantly higher ADG ($p < 0.05$) between days 8 to 16, 16 to 22 and during the overall starter period ($p < 0.01$) and a significantly improved FCR ($p < 0.05$) during the starter period compared with pigs offered diets containing no avilamycin. The pigs offered diets containing avilamycin had a significantly ($p < 0.05$) higher ADG and feed intake from day 22 to 29 than pigs offered diets containing no avilamycin.

There was a significant interaction ($p < 0.05$) between lactofeed and avilamycin for ADG from day 29 to 39 and during the overall transition period. The inclusion of avilamycin at the low level of lactofeed had no significant effect on ADG. However, at the high level of lactofeed, diets containing avilamycin had a significantly higher ADG than pigs offered diets containing no avilamycin. The pigs offered diets containing the high level of lactofeed had a greater feed intake ($p < 0.05$) during the transition period.

The pigs offered diets containing the high level of lactofeed had a higher ADG ($p < 0.01$), a higher feed intake ($p < 0.05$) and an improved FCR ($p < 0.05$) during the combined starter-transition period

Table 3. Effect of lactofeed (LF70) and avilamycin on pig performance (LSM ± SEM)

Lactofeed (g kg^{-1})	175	175	350	350		Significance		
Avilamycin	−	+	−	+	SEM	LF 70	Avilamycin	LF70 × avilamycin
Average daily gain (kg day^{-1})								
Daily gain 0–8 days	0.048	0.109	0.149	0.163	0.0284	ns	ns	*
Daily gain 8–16 days	0.286	0.322	0.319	0.370	0.0182	*	*	ns
Daily gain 16–22 days	0.436	0.508	0.509	0.549	0.0240	*	*	ns
Starter daily gain (0–22 days)	0.292	0.333	0.333	0.368	0.0130	**	*	ns
Daily gain 22–29 days	0.450	0.457	0.420	0.508	0.0230	ns	*	ns
Daily gain 29–39 days	0.526	0.555	0.566	0.663	0.0193	***	**	*
Transition daily gain (22–39 days)	0.495	0.514	0.506	0.599	0.0188	**	**	*
Starter-transition (0–39 days)	0.360	0.400	0.404	0.464	0.0132	**	**	ns
Feed Intake (kg day^{-1})								
Feed intake 0–8 days	0.156	0.191	0.247	0.208	0.0274	ns	ns	ns
Feed intake 8–16 days	0.453	0.480	0.509	0.489	0.0237	ns	ns	ns
Feed intake 16–22 days	0.494	0.527	0.529	0.585	0.0244	ns	ns	ns
Starter feed intake (0–22 days)	0.448	0.454	0.473	0.478	0.0210	ns	ns	ns
Feed intake 22–29 days	0.854	0.839	0.889	0.920	0.0318	ns	*	ns
Feed intake 29–39 days	1.050	1.016	1.134	1.187	0.0360	**	ns	ns
Overall transition (22–39 days)	0.960	0.937	1.024	1.066	0.0337	*	ns	ns
Starter-transition (0–39 days)	0.713	0.691	0.742	0.768	0.0240	*	ns	ns
Food conversion ratio (kg kg^{-1})								
FCR 0–8 days	3.24	1.75	1.65	1.27	0.450	ns	ns	ns
FCR 8–16 days	1.58	1.56	1.63	1.37	0.057	ns	*	*
FCR 16–22 days	1.82	1.65	1.65	1.61	0.103	ns	ns	ns
Starter FCR (0–22 days)	2.21	1.65	1.64	1.41	0.061	*	**	ns
FCR 22–29 days	1.81	1.70	2.00	1.68	0.091	ns	ns	ns
FCR 29–39 days	2.00	1.84	2.05	1.78	0.054	ns	**	ns
Overall transition (22–39 days)	1.91	1.78	2.02	1.73	0.064	ns	**	ns
Starter-transition (0–39 days)	2.08	1.70	1.80	1.55	0.039	*	***	ns

* = ($p < 0.05$); ** = ($p < 0.01$); *** = ($p < 0.001$). ns = not significant.

than pigs offered diets containing the low inclusion of lactofeed. The pigs offered diets containing avilamycin had an improved FCR during the transition period ($p < 0.01$) and the combined starter-transition period ($p < 0.001$) compared with pigs offered non-medicated diets.

Digestibility

The effect of lactofeed and avilamycin on nutrient digestibility of the starter and transition diets is presented in Table 4. The pigs offered diets containing the high inclusion of lactofeed had a significantly higher ($p < 0.001$) apparent digestibility of dry matter (DM) and organic matter (OM) than pigs offered diets containing the low inclusion of lactofeed during the starter period. The inclusion of lactofeed had no significant effect ($p > 0.05$) on protein digestibility, although it did tend to increase it numerically. The pigs offered diets containing avilamycin had a significantly higher apparent digestibility ($p < 0.001$) of DM, protein and OM than pigs offered diets containing no avilamycin during the starter period.

There was a significant interaction ($p < 0.05$) between lactofeed level and avilamycin in gross energy and ash digestibility, as well as DE content during the starter period. The pigs offered diets containing avilamycin at the low inclusion of lactofeed had a significantly higher ($p < 0.001$) ash and gross energy digestibility and DE content than pigs offered diets containing no avilamycin. However at the high inclusion of lactofeed the inclusion of avilamycin had no significant effect ($p > 0.05$) on ash and gross energy digestibility or DE content of the diet.

The inclusion of lactofeed had no significant effect ($p > 0.05$) on the apparent digestibility of DM, OM, protein, ash and gross energy during the transition period. The pigs offered diets containing avilamycin had a significantly higher apparent digestibility ($p < 0.001$) of DM, OM protein, ash and gross energy than pigs offered diets containing no avilamycin. There was a significant interaction between lactofeed and avilamycin ($p < 0.05$) in the DE content of the transition diet. The inclusion of avilamycin at the low level of lactofeed significantly increased the DE content of the diet ($p < 0.001$) compared with no avilamycin inclusion. However the inclusion of avilamycin at the high level of lactofeed had no significant effect ($p > 0.05$) on the DE content of the diet.

Experiment 2

Pig performance

The effect of lactofeed level and zinc oxide on ADG, feed intake and FCR during the starter, transition period and during the combined starter-transition period is shown in Table 5.

Table 4. Effect of lactofeed (LF70) and avilamycin on the apparent digestibility coefficients of starter and transition diets (LSM ± SEM)

Lactofeed ($g\,kg^{-1}$)	Starter diets 175	175	350	350	SEM	LF70	Avilamycin	LF70 × avilamycin	Transition diets 87.5	87.5	175	175	SEM	LF70	Avilamycin	LF70 × avilamycin
Avilamycin	−	+	−	+					−	+	−	+				
Dry matter	0.823	0.853	0.853	0.869	0.0053	***	***	ns	0.828	0.863	0.833	0.860	0.0059	ns	***	ns
Organic matter	0.826	0.859	0.859	0.877	0.0058	***	***	ns	0.827	0.863	0.829	0.858	0.0068	ns	***	ns
Crude protein	0.741	0.808	0.779	0.806	0.0112	ns	***	ns	0.730	0.835	0.709	0.816	0.0148	ns	***	ns
Ash	0.423	0.514	0.592	0.615	0.0015	***	**	*	0.468	0.550	0.511	0.559	0.0153	ns	***	ns
Gross energy	0.786	0.830	0.828	0.845	0.0067	***	***	*	0.791	0.832	0.800	0.831	0.0076	ns	***	ns
DE content ($MJ\,kg^{-1}$)	15.95	16.93	16.81	17.00	0.1669	*	**	*	16.43	17.40	16.34	16.78	0.1201	*	***	*

* = ($p < 0.05$); ** = ($p < 0.01$); *** = ($p < 0.001$). ns = not significant.

The pigs offered diets containing the high inclusion of lactofeed had a significantly higher ADG ($p < 0.05$) from day 0 to 8 and during the overall starter period and an improved FCR during the starter period ($p < 0.05$) compared with pigs on low inclusion of lactofeed. The pigs offered diets containing zinc oxide had a significantly higher daily gain from day 8 to 16 ($p < 0.01$), 16 to 22 ($p < 0.05$) and during the overall starter period ($p < 0.05$) and a significantly higher feed intake ($p < 0.05$) from day 16 to 22 compared with pigs offered diets containing no zinc oxide. The pigs offered diets containing zinc oxide had a significantly improved FCR from day 8 to 16 ($p < 001$), day 29 to 39 and during the overall starter period ($p < 0.05$) and starter-transition period ($p < 0.05$) compared with pigs offered diets containing no zinc oxide. There was no significant lactofeed inclusion level × zinc oxide interaction in any performance variable measured.

Digestibility

The effect of lactofeed and zinc oxide on nutrient digestibility of the starter and transition diet is presented in Table 6. The pigs offered starter diets containing the high level of lactofeed had a significantly higher apparent digestibility of DM ($p < 0.001$), protein ($p < 0.01$), gross energy ($p < 0.001$) and OM ($p < 0.001$), as well as DE content ($p < 0.01$) compared with pigs offered diets containing the low inclusion of lactofeed. The inclusion of zinc oxide had no significant effect ($p > 0.05$) on the digestibility of DM, OM, protein and gross energy or on the DE content of the diet. There was a significant interaction between lactofeed and zinc oxide in ash digestibility ($p < 0.05$) of the starter diet. The pigs offered diets containing zinc oxide at the low level of lactofeed had a significantly higher ash digestibility ($p < 0.05$) than pigs offered diets containing no zinc oxide. However at the high level of lactofeed the inclusion of zinc oxide had no significant effect ($p > 0.05$) on ash digestibility.

The pigs offered diets containing the high level of lactofeed in the transition diet had a significantly higher ash digestibility ($p < 0.05$) than pigs offered diets containing the low level of lactofeed. The pigs offered diets containing zinc oxide had a significantly higher protein digestibility ($p < 0.01$) than pigs offered diets containing no zinc oxide.

DISCUSSION

In both experiments 1 and 2 there was a significant increase in daily gain and an improvement in FCR during the starter period as the level of lactofeed increased. These findings are in agreement with previous authors who noted an increased performance with increasing lactose inclusion levels during the initial two weeks postweaning.[10,21] In contrast to the present experiment, particularly during the starter period, the improved performance noted was due to an increased feed intake. In both experiments lactofeed was substituted for maize in the starter diet.

Table 5. Effect of lactofeed and zinc oxide on pig performance (LSM ± SEM)

Lactofeed ($g\,kg^{-1}$)	175	175	350	350		Significance	
Zinc oxide	−	+	−	+	SEM	Lactofeed	Zinc oxide
ADG ($kg\,day^{-1}$)							
Daily gain 0–8 days	0.031	0.096	0.118	0.122	0.024	*	ns
Daily gain 8–16 days	0.283	0.354	0.316	0.403	0.032	ns	**
Daily gain 16–22 days	0.431	0.518	0.503	0.526	0.024	ns	*
Starter daily gain (0–22 days)	0.289	0.351	0.329	0.363	0.014	*	***
Daily gain 22–29 days	0.446	0.450	0.413	0.448	0.024	ns	ns
Daily gain 29–39 days	0.524	0.590	0.564	0.564	0.021	ns	ns
Overall transition (22–39 days)	0.492	0.533	0.502	0.514	0.019	ns	ns
Starter-transition (0–39 days)	0.377	0.430	0.404	0.428	0.016	ns	**
Feed Intake ($kg\,day^{-1}$)							
Feed intake 0–8 days	0.152	0.213	0.235	0.205	0.031	ns	ns
Feed intake 8–16 days	0.449	0.495	0.505	0.503	0.027	ns	ns
Feed intake 16–22 days	0.490	0.551	0.523	0.551	0.018	ns	*
Starter feed intake (0–22 days)	0.445	0.475	0.469	0.475	0.022	ns	ns
Feed intake 22–29 days	0.851	0.916	0.887	0.875	0.027	ns	ns
Feed intake 29–39 days	1.049	1.113	1.135	1.062	0.042	ns	ns
Overall transition (22–39 days)	0.968	1.032	1.033	0.985	0.034	ns	ns
Starter-transition (0–39 days)	0.711	0.744	0.740	0.723	0.026	ns	ns
FCR ($kg\,kg^{-1}$)							
FCR 0–8 days	4.90	2.21	1.99	1.68	0.821	ns	ns
FCR 8–16 days	1.58	1.39	1.59	1.24	0.041	ns	***
FCR 16–22 days	1.13	1.06	1.03	1.04	0.090	ns	ns
Starter FCR (0–22 days)	1.53	1.35	1.42	1.30	0.078	*	*
FCR 22–29 days	1.90	2.03	2.14	1.95	0.133	ns	ns
FCR 29–39 days	2.00	1.88	2.01	1.88	0.067	ns	*
Transition FCR (22–39 days)	1.96	1.93	2.05	1.91	0.081	ns	ns
Starter-transition FCR (0–39 days)	1.88	1.73	1.83	1.68	0.054	ns	*

* = ($p < 0.05$); ** = ($p < 0.01$); *** = ($p < 0.001$).
ns = there was no significant lactofeed level by zinc oxide interaction.

The digestive system of the newly weaned pig is still inadequate to digest the starch from maize up to eight weeks of age.[10] However pigs can efficiently utilise lactose throughout the starter period.[10]

It is not surprising that lactofeed improves daily gain and feed efficiency in the newly weaned pig. Lactofeed contains $700\,g\,kg^{-1}$ of lactose. A large proportion of the lactose is readily fermented to lactic acid by *Lactobacilli*.[13] There is a reduction in intestinal lactase activity around three to four weeks of age[22] and thereafter lactase activity cannot be restimulated to any significant extent in the pig by addition of lactose to the diet. Research has shown that older pigs had only sufficient intestinal lactase activity to digest 40% of lactose ingested, the remainder being available for fermentation.[23] The resultant acidification restricts the growth of undesirable acid-intolerant bacteria[13] which should improve both growth rates and feed efficiency.[2] Recent research from this laboratory has shown a direct relationship between large intestinal pH and lactofeed inclusion, indicating that lactose was reaching the hind-gut.[24] There were also increased lactate concentrations observed in the colon of pigs fed the high lactofeed diets.[24] The lower gut pH, as a result of the high lactofeed inclusion, corresponded with increases in lactobacilli, reductions in coliforms and improved intestinal morphology.[24]

The inclusion of avilamycin resulted in 12.5% increase in growth rate during the overall starter period. This increase in daily gain is slightly lower than the 16.4% reported by previous authors when using in-feed antibiotics.[25] These authors reported a 16.4% improvement in daily gain and a 6.9% reduction in the amount of feed required per unit gain. The difference in improvement observed between experiments with in-feed antibiotics may result from various modes of action of antibiotics, varying age and environmental conditions of the piglets. The response of animals to antibiotics may vary depending on the disease load and environment in which the animals are kept.[25]

The inclusion of antibiotics in feed improves feed efficiency by reversing the microbial-induced growth depression, by increasing the utilisation of nutrients and by reducing maintenance costs of the gastro-intestinal system.[26,27] Recent research has shown that avilamycin reduces gastro-intestinal bacterial populations and thus facilitates improved growth.[27] Reducing the numbers of bacteria in the gut would decrease competition between the host and the gut bacteria for dietary components, thus increasing nutrient availability to the host for growth.[27]

The inclusion of avilamycin had no significant effect on daily gain at the low level of lactofeed

Table 6. Effect of lactofeed and zinc oxide on the apparent digestibility coefficients of starter and transition diets (LSM ± SEM)

	Starter diets								Transition diets							
Lactofeed (g kg^{-1})	175	175	350	350	SEM	LF70	Zinc oxide	LF70 × Zinc oxide	87.5	87.5	175	175	SEM	LF70	Zinc oxide	LF70 × Zinc oxide
Zinc oxide	−	+	−	+					−	+	−	+				
Dry matter	0.823	0.823	0.853	0.857	0.0068	***	ns	ns	0.828	0.828	0.833	0.830	0.0044	ns	ns	ns
Organic matter	0.826	0.828	0.859	0.869	0.0070	***	ns	ns	0.822	0.824	0.829	0.827	0.0050	ns	ns	ns
Crude protein	0.741	0.753	0.779	0.805	0.0119	**	ns	ns	0.731	0.761	0.709	0.772	0.0136	ns	**	ns
Ash	0.423	0.486	0.592	0.870	0.0157	***	ns	*	0.468	0.472	0.511	0.495	0.0123	*	ns	ns
Gross energy	0.786	0.798	0.828	0.834	0.0085	***	ns	ns	0.791	0.790	0.800	0.797	0.0058	ns	ns	ns
DE content (MJ kg^{-1})	15.95	16.07	16.81	16.60	0.0018	**	ns	ns	16.43	16.40	16.34	16.19	0.1267	ns	ns	ns

* = ($p < 0.05$); ** = ($p < 0.01$); *** = ($p < 0.001$).
ns = not significant.

inclusion. However at the high level of lactofeed, the inclusion of avilamycin resulted in an increase in daily gain compared with pigs offered diets containing no avilamycin. It would appear that there is an additive response between lactose level and avilamycin inclusion. Lactose is readily fermented by *lactobacilli*, which is a Gram-positive bacterium.[26] It is therefore possible that high inclusion levels of lactose may promote excess *lactobacilli*. In rapidly growing young animals, the gastro-intestinal tract and the skeletal musculature draw from the same limited supply of nutrients and are in effect competitors for the deposition of nutrients.[28] As much as 6% of the net energy in pig diets can be lost due to bacterial utilisation of glucose in the small intestine[29] and *lactobacilli* require amino acids in relatively similar proportional amounts as the pig.[25,30] When avilamycin was added to the high lactofeed inclusion there may have been a nutrient sparing effect.

There was an increase in feed intake with increasing levels of lactofeed during the transition period and during the entire experiment. In experiment 1, the pigs offered diets containing the high inclusion of lactofeed had an increased performance compared to pigs offered the low inclusion of lactofeed. Lactose is highly digestible and is utilised more efficiently than more complex carbohydrates such as starch in grains.[31] The increase in feed intake as a result of lactofeed may be due to two reasons. First, there is a direct relationship between feed digestibility and feed intake in the young pig[32] and, second, lactose has an effect on feed palatability,[10] which can be related to its contribution to feed sweetness.

The inclusion of avilamycin resulted in an improvement in feed efficiency during the starter period, transition period and during the entire experiment. It is evident that the inclusion of lactofeed improved performance when formulated with avilamycin. The inclusion of high lactofeed is efficient enough in promoting growth to replace avilamycin in low lactofeed diets; however, it is not efficient enough in promoting growth to replace avilamycin at high lactofeed inclusion.

In experiment 2 the inclusion of zinc oxide in the starter period was also effective in promoting growth and improving feed efficiency. The inclusion of zinc oxide gave a proportional increase in daily gain of 15% due to a 11% improvement in FCR compared with no zinc oxide inclusion. Other authors have also noted the improved performance in weanling pigs fed pharmological concentrations (3000 ppm) of zinc oxide.[4–6] In agreement with the present experiment previous authors[4,6] reported a similar proportional increase in daily gain of 12 and 13% respectively when 3000 ppm of zinc oxide was added to a starter diet.

Although the supplementation of starter diets with zinc oxide usually results in an increased growth performance, previous experiments have reported variable results in feed intake and gain to feed responses. The results of the present experiment are in agreement with previous findings,[5,33] reported that the improved growth performance with zinc oxide supplementation was due to an improved feed efficiency. In the present experiment no improvement in feed intake was observed due to zinc oxide inclusion. However previous experiments have noted an increased feed intake due to zinc oxide inclusion in starter diets.[4]

The improved gain to feed efficiency observed in the present experiment was not due to an improved nutrient digestibility and therefore it must be due to an improved gut health or a decrease in diarrhoea, which is also associated with zinc oxide supplementation. Previous authors also noted that the incidence and severity of diarrhoea of unknown origin was reduced in pigs from a pathogen free herd fed 2500 ppm of zinc or 4000 ppm of zinc oxide.[7] It has been reported that zinc in pharmological doses plays a significant role in killing microbes but it does not exert a pharmological action on circulating neutrophils.[34] Even in the absence of diarrhoea the enteric flora of the piglet is severely compromised at weaning. The enteric flora recovers within two or three weeks unless the pig develops postweaning diarrhoea. However the addition of high amounts of zinc oxide may lessen the period with disturbed enteric flora.[35]

The reduced effectiveness of zinc oxide during the transition period is not surprising as zinc oxide is most effective in promoting growth in the immediate period postweaning and declines with age. The feeding of pharmological concentrations of zinc oxide during the initial two weeks of postweaning is equivalent to that achieved with pharmological concentrations of zinc oxide during a 28-day starter period.[33] The inclusion of zinc resulted in an improvement in daily gain and feed efficiency during the overall experiment. This proves how effective zinc oxide was as promoting growth during the starter period. The inclusion of lactofeed is not as efficient in promoting growth in weanling pigs as zinc oxide.

Increasing the lactofeed level in the starter diet in both experiments resulted in an increase in the apparent digestibility of dry matter and organic matter. In experiment 2 increasing the level of lactofeed also resulted in an increase in apparent protein and energy digestibility. The inclusion of dried whey in weanling diets has consistently improved growth performance as a result of increased dry matter intake and digestibility of energy and nitrogen compared with pigs fed maize, soya bean meal diets.[8–11] Since lactose represents 70% of the dry matter in lactofeed it is not surprising that it would increase performance by increasing apparent nutrient digestibility. The inclusion of milk in the postweaning diet can maintain the structure and function of the small intestine.[36] The inclusion of lactose prevents morphological changes in the gut postweaning[24] which leads to a reduced digestive capacity. With increasing lactofeed, there is also an increased fermentation of lactose to lactic acid,[24] which may be sufficient to compensate for the deficiency in HCl production by the immature gastric secretary cells of the weanling pig.[13] The resultant acidification stimulates proteolytic activity assisting in the gastric proteolysis and nutrient digestibility.[13]

In both experiments the inclusion of lactofeed in transition diets had no significant effect on nutrient digestibility. This indicates a decreased reliance of the pig on lactic acid to promote digestion. This is in agreement with previous authors,[37] which noted that the gastric secretion of the weanling pig was fully developed by eight weeks of age.

The inclusion of avilamycin in experiment 1 resulted in an improvement in nutrient digestibility of both the starter and transition diet. The inclusion of antibiotics in weanling diets causes a reduction in the thickness of the intestinal wall and an overall decrease in the total gut mass.[38] The increased gut wall thickness is thought to be caused by the inhabitant bacteria which either damage intestinal tissue or produce toxins that, in turn, damage the tissue.[38] A thinner gut wall results in greater nutrient absorption.[39]

In conclusion the supplementation of starter diets with high levels of lactofeed resulted in increased daily gain, improved feed efficiency and improved nutrient digestibility. The inclusion of avilamycin resulted in increased daily gain, improved feed efficiency and improved nutrient digestibility compared with no avilamycin inclusion. The inclusion of zinc oxide resulted in a significant increase in daily gain and feed efficiency during the overall experiment compared with no zinc oxide inclusion.

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