Effect of cyadox on growth and nutrient digestibility in weanling pigs

Y. Wang, Z. Yuan[#], H. Zhu, M. Ding and S. Fan
MOA Key Laboratory of Food Safety Evaluation and MOA Reference Laboratory for Test of Veterinary Drug Residues, Huazhong Agricultural University, Wuhan, Hubei 430070, P. R. China

Abstract

The effect of cyadox on growth and apparent digestibility of nutrients in weanling pigs was investigated. Cyadox (2-formylquinoxaline-N[1],N[4]-dioxide cyanocetylhydrazone) is a derivative of quinoxaline-1, 4-dioxide, a growth promoting antimicrobial agent that is used in pig production. Seventy-five crossbred weanling barrows were randomly assigned to three treatments with five replicates per treatment. The three dietary treatments consisted of an unmedicated diet (control), a diet containing 100 mg/kg of cyadox and a diet containing 100 mg /kg of olaquindox. The body weight and feed consumption of the pigs were measured weekly for the 4-week experimental period. During week 4 a digestibility study was conducted, and faecal grab samples were collected for six days from each pen. The pigs fed cyadox had significantly higher average daily gains and improved feed conversion efficiencies compared to the control. Cyadox did not affect average daily feed intake. The apparent digestibility of dry matter, crude protein, ether extract, nitrogen free extract, calcium, phosphorus and gross energy was significantly increased in the cyadox-fed pigs above the control. Inclusion of cyadox significantly improved the apparent digestibility of iron, copper, zinc and manganese, and that of several essential and nonessential amino acids. It is suggested that the growth promoting effect of cyadox may be attributed to the improvement in the apparent digestibility of dietary nutrients.

Keywords: Cyadox, pigs, average daily gain, feed conversion efficiency, digestibility, amino acids, mineral elements
[#] Corresponding author. E-mail: yuan5802@public.wh.hb.cn

Introduction

It has been recorded that dietary antimicrobial agents can promote growth and improve efficiency of feed utilization in pigs (Hays, 1981; Zimmerman, 1986), and can increase absorption and retention of nutrients by decreasing the faecal excretion of these nutrients (Visek, 1978; Roth & Kirchgessner, 1993; Wuethrich *et al*., 1998). The quinoxaline-1, 4-dioxide compounds, olaquindox and carbadox, have been used in pigs as growth promoting agents for improvement of weight gain and feed efficiency, and as antibacterial drugs for the prevention and control of dysentery and bacterial enteritis in pigs. Feeding sub-therapeutic levels of carbadox increased average daily gain (ADG), muscle growth and carcass muscle content in pigs (Stahly *et al*., 1994). The product also improved the apparent ileal digestibility of several essential and non-essential amino acids, and increased the apparent ileal and faecal digestibility of ether extract in growing pigs (Partanen *et al*., 2001). Roof & Mahan (1982) reported that carbadox increased growth rate and nitrogen retention, and reduced copper retention and liver copper concentrations in pigs, while Hamada *et al*. (1988) and Li *et al*. (2000) concluded that olaquindox increased growth rate by increasing the absorption of iron and amino acids.

Cyadox (2-formylquinoxaline-N[1],N[4]-dioxide cyanocetylhydrazone) is a new derivative of quinoxaline-1, 4-dioxide, similar to carbadox and olaquindox. It has been used as a feed additive for pigs, calves and poultry (Graaf & Spierenburg, 1988). It increased ADG and efficiency of feed utilization in weaned pigs (Broz & Sevcik, 1979; Broz *et al*., 1979) with less side effects and less toxic effects than carbadox and olaquindox (Cihak & Srb, 1983; Cihak & Vontorkova, 1983; 1985). Dietary inclusion of cyadox increased the concentrations of calcium and potassium in the breast and thigh muscles of chicken (Tokosova, 1989a) and increased breast muscle copper concentration and feather manganese concentration, but decreased the concentration of manganese in both breast and thigh muscles (Tokosova, 1989b). Some evidence exists that cyadox may affect absorption and retention of important macro and trace elements. However, the effect of dietary cyadox on the absorption and retention of amino acids and other nutrients has never been investigated.

The object of the current study was to determine the effect of cyadox on growth performance and apparent digestibility of amino acids, mineral elements and conventional nutrients in weanling pigs.

Materials and Methods

Seventy-five Landrace x Large White crossbred barrows, weaned at 35 days of age, were acquired from a commercial pig farm. The animals, weighing 10.3 ± 0.1 kg at the start of the 7-day adaptation period, were fed a basal diet containing no antibiotics. At the age of 42 d the piglets entered the experiment. Pigs were randomly allotted to pens with five pigs per pen. A total of 15 pens was randomly allotted to one of three dietary treatments: 1) control diet without any antimicrobial substance; 2) an olaquindox diet containing 100 mg olaquindox/kg and 3) a cyadox diet containing 100 mg cyadox/kg. All diets were formulated to meet or exceed the nutrient requirements for growing pigs according to the NRC (1998) standards. The ingredient and chemical composition of the diets are presented in Table 1, 2 and 3.

Table 1 Ingredients of the experimental diets (as fed basis)

Ingredients %	Treatments		
	Control	Olaquindox	Cyadox
Maize	61.6	61.6	61.6
Soyabean meal	27.0	27.0	27.0
Fish meal	5.0	5.0	5.0
FEEDOMEL[a]	1.0	1.0	1.0
Soyabean oil	2.0	2.0	2.0
Salt	0.3	0.3	0.3
Choline chloride	0.1	0.1	0.1
Dicalcium phosphate	1.4	1.4	1.4
Limestone	0.6	0.4	0.4
Mineral and vitamin premix[b]	1	1	1
Medicinal premix[c]	-	0.2	0.2

[a] FEEDOMEL, manufactured by Holland, contained 350 g crude protein/kg, and 480 g carbohydrates/kg
[b] Mineral, vitamin and amino acid premixes contained the following per kg of feed: Fe - 100 mg; Zn - 100 mg; Mn - 60 mg; Cu - 20 mg; Se - 0.30 mg; I - 0.30 mg; Co - 0.30 mg; vitamin A - 2700 IU; vitamin D_3 - 560 IU; vitamin E - 10 mg; vitamin K_3 - 1.5 mg; thiamine - 1.5 mg; riboflavin - 7.5 mg; vitaminB_6 - 1.5 mg; vitaminB_{12} - 15 µg; niacin amide - 40 mg; calcium pantothenate - 12.5 mg; folic acid - 0.5 mg; biotin - 50 µg; lysine - 2 g
[c] Medicinal premix provided 100 mg of olaquindox or cyadox per kg of feed

Table 2 Nutrient and mineral element composition of the experimental diets (analysed, as-fed basis)

Item	Treatments		
	Control	Olaquindox	Cyadox
Dry matter, g/kg	875.8	878.6	875.2
Crude protein, g/kg	212.3	215.6	214.0
Ether extract, g/kg	34.6	36.6	33.4
Crude fibre, g /kg	32.3	35.5	31.2
Nitrogen free extract, g/kg	538.2	532.9	537.9
Gross energy, MJ/kg	16.96	17.05	16.96
Calcium, g/kg	12.1	12.6	13.1
Phosphorus, g/kg	7.0	7.0	7.2
Copper, mg/kg	18.59	18.14	18.72
Iron, mg /kg	242.88	243.05	242.72
Zinc, mg/kg	143.03	142.24	147.21
Manganese, mg/kg	63.88	61.43	66.24

Pigs were housed in a nursery room. The temperature of the room was controlled at about 20 °C. All pigs received their diets three times a day (08:00, 13:00 and 18:00) and had free access to water. Pig body weight and feed consumption were measured weekly for the 4-week experimental period. Care of the animals was in accordance with the "Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching" (Consortium, 1988).

Faeces were collected during week 4 of the experiment. Fresh faecal grab samples were randomly taken from each pen to determine the digestibility of nutrients, gross energy, mineral elements and amino acids. Faeces samples were collected six times. Sampling alternated between morning and afternoon over the 6-day period. Faecal samples per pen were pooled, sealed in plastic bags and frozen at –20 °C pending analyses. A sample of each diet was collected, dry matter (DM) content was determined and was kept for subsequent chemical analyses. Acid insoluble ash (AIA) was used as an indigestible marker to calculate digestibility coefficients (McCarthy *et al*., 1974).

Table 3 Amino acid composition of the experimental diets (analysed, as-fed basis)*

Item	Treatments		
	Control	Olaquindox	Cyadox
Alanine, g/kg	11.9	11.2	11.5
Arginine, g/kg	14.5	15.1	14.9
Aspartic acid, g/kg	21.1	22.1	22.4
Cystine, g/kg	2.4	2.4	2.6
Glutamic acid, g/kg	42.8	42.9	42.2
Glycine, g/kg	10.8	10.1	10.3
Histidine, g/kg	5.5	5.6	5.6
Isoleucine, g/kg	10.1	10.2	10.2
Leucine, g/kg	19.1	19.1	19.2
Lysine, g/kg	14.1	13.1	14.4
Methionine, g/kg	5.2	4.8	5.0
Phenylalanine, g/kg	11.8	12.0	11.9
Valine, g/kg	11.5	11.5	11.7
Proline, g/kg	9.9	10.6	9.9
Serine, g/kg	10.8	10.7	10.2
Threonine, g/kg	8.6	8.6	9.0
Tyrosine, g/kg	7.1	7.7	7.2
Tryptophan, g/kg	2.8	2.8	2.8
Total amino acids, g/kg	217.2	217.7	218.2

* The concentration of tryptophan was calculated, based on Chinese Feed Database (2000) values of included ingredients. Total amino acid values do not include tryptophan

Faecal samples were dried at 60 °C for 48 h and then allowed to equilibrate at room temperature for 24 h. After weighing, an entire sample was ground through a 0.45 mm sieve and stored at room temperature, pending chemical analyses. All samples were analysed in duplicate. Dry matter, crude protein (Kjeldahl, N × 6.25), ether extract, crude fibre, ash, calcium, phosphorus and trace elements in feed and faeces were analysed following official methods of analysis (AOAC, 2000). Mineral element concentrations were determined using atomic absorption spectrophotometry (model Z-5000, HITACHI, Japan), gross energy using a nonadiabatic bomb calorimeter (model GR3500, Changsha, P. R. China) and amino acids with a HITACHI 835-50 amino acid analyser. The AIA concentrations of the feed and faeces samples were measured after ashing the samples and treating the ash with boiling 4 M HCl (Siriwan *et al*., 1993). Apparent digestibility was calculated with AIA as the indigestible marker, as follows:

$$\text{Apparent digestibility} = 100 - \left(\frac{AIA_F}{AIA_D}\right) \times \left(\frac{N_D}{N_F}\right) \times 100$$

Where AIA_F is the concentration of AIA in feed (mg/kg DM), AIA_D is the concentration of AIA in faeces (mg/kg DM), N_D the concentration of nutrient in faeces (g/kg DM) and N_F is the concentration of nutrient in feed (g/kg DM).

Data were analysed by ANOVA as a completely randomised design using the GLM procedures of SAS (1989). Pen served as the experimental unit for all parameters measured. Significance of differences between treatment means was determined using the least significant difference procedure. Effects were considered significant at P < 0.05. Probability values between P > 0.05 and P < 0.10 were considered trends, and probability values of P > 0.10 were considered not significant.

Results

The effects of cyadox and olaquindox on ADG, feed consumption and feed conversion efficiency (FCE, weight gain/feed intake) are shown in Table 4. Throughout the study diet composition did not affect (P > 0.10) average daily feed intake. Cyadox improved ADG by 19.9% in week 1 (P < 0.002), by 16.5% in week 2 (P < 0.001), by 19.3% in week 3 (P < 0.001) and by 21.4% in week 4 (P < 0.001) above the control. Improvement in FCE in the cyadox treatment above the control was 16.1% (P < 0.002), 13.3% (P < 0.001), 25.9% (P < 0.001), and 20.2% (P < 0.002), during the respective weeks. Olaquindox inclusion increased ADG above the control by 11.1% (P < 0.04) in week 3, 7.0% (P < 0.05) in week 4, 9.2% (P < 0.10) in week 1 and 4.0% (P < 0.10) in week 2 (P > 0.10). Compared to the control, FCE of the pigs fed olaquindox was better (P < 0.01) in week 2 and tended to increase by 8.0% (P < 0.08) in week 1, 11.5% (P < 0.06) in week 3 and 9.1% (P > 0.10) in week 4. Moreover, in weeks 2 and 4 ADG was higher (P < 0.01) in cyadox-fed pigs compared to the olaquindox group, and showed a tendency to be higher in weeks 1 (P < 0.06) and 3 (P < 0.10). Feed conversion efficiency showed a tendency to be better for the pigs fed cyadox compared to olaquindox in weeks 1 (P < 0.08) and 4 (P < 0.06), and showed significant differences (P < 0.05) during weeks 2 and 3. Overall, ADG was higher (P < 0.01) in the cyadox and olaquindox groups compared to the control. Similarly, FCE's during the four-week study was 20.1% (P < 0.001) better in the cyadox group and 9.2% (P < 0.02) better in the olaquindox group than in the control.

Table 4 Effects of cyadox and olaquindox on the average daily gain (ADG), average daily feed intake (ADFI) and feed conversion efficiency (FCE, weight gain/feed intake) of weanling pigs*

Item	Treatments			SEM	Probability
	Control	Olaquindox	Cyadox		
Initial BW, kg	12.06 ± 0.52	12.05 ± 0.60	12.06 ± 0.44	0.331	0.9991
ADG, g /d					
Wk 1	261 ± 22[a]	285 ± 19[ab]	313 ± 20[b]	13.1	0.0071
Wk 2	346 ± 29[a]	360 ± 23[a]	403 ± 22[b]	13.8	0.0036
Wk 3	450 ± 30[a]	500 ± 35[b]	537 ± 33[b]	20.6	0.0040
Wk 4	486 ± 48[a]	520 ± 22[b]	590 ± 26[c]	15.4	0.0001
Wk 1 to 4	386 ± 14[a]	416 ± 14[b]	461 ± 17[c]	9.7	0.0001
ADFI, g /d					
Wk 1	447 ± 20	451 ± 22	461 ± 20	13.2	0.5786
Wk 2	588 ± 30	574 ± 27	605 ± 30	18.6	0.2682
Wk 3	1058 ± 51	1057 ± 48	1006 ± 42	29.8	0.1797
Wk 4	1132 ± 49	1113 ± 65	1142 ± 56	36.0	0.7175
Wk 1 to 4	806 ± 21	799 ± 28	804 ± 14	13.8	0.8573
FCE, g /g					
Wk 1	0.584 ± 0.042[a]	0.631 ± 0.045[a]	0.678 ± 0.027[b]	0.024	0.0083
Wk 2	0.588 ± 0.019[a]	0.627 ± 0.022[b]	0.666 ± 0.020[c]	0.013	0.0002
Wk 3	0.425 ± 0.020[a]	0.474 ± 0.045[a]	0.535 ± 0.039[b]	0.023	0.0017
Wk 4	0.430 ± 0.035[a]	0.469 ± 0.044[a]	0.517 ± 0.028[b]	0.023	0.0083
Wk 1 to 4	0.478 ± 0.018[a]	0.522 ± 0.029[b]	0.574 ± 0.026[c]	0.016	0.0002

* Data are the means of five replicates of five barrows per replicate
[a-c] Means within rows with different superscripts differ at P < 0.05
BW – body weight

The effects of cyadox and olaquindox inclusion to the diet on apparent digestibility of macro nutrients and energy are shown in Table 5. The apparent digestibility of DM, crude protein, crude fibre, ether extract and energy in the cyadox-fed pigs was higher (P < 0.001) than those in the control and the olaquindox-fed pigs. The apparent digestibility of nitrogen free extract (NFE) in pigs fed cyadox was greater than those in the control (P < 0.001) and olaquindox (P < 0.03) groups. The supplementation of olaquindox increased the apparent digestibility of DM (P < 0.005), crude protein (P < 0.05), crude fibre (P < 0.001), ether extract (P < 0.009) and energy (P < 0.03), compared to the control, and tended to increase (P < 0.07) the apparent digestibility of NFE.

Table 5 Effects of cyadox and olaquindox on the apparent digestibility (%) of nutrients and energy* in pigs

Item	Treatments			SEM	Probability
	Control	Olaquindox	Cyadox		
Dry matter	83.1 ± 0.5[a]	84.6 ± 0.8[b]	87.4 ± 0.7[c]	0.44	0.0001
Crude protein	78.4 ± 1.3[a]	80.6 ± 1.6[b]	85.4 ± 1.8[c]	1.01	0.0001
Crude fibre	57.2 ± 2.8[a]	63.9 ± 2.2[b]	66.1 ± 1.7[c]	1.44	0.0001
Ether extract	57.0 ± 2.0[a]	61.8 ± 3.1[b]	71.4 ± 2.0[c]	1.52	0.0001
NFE [2]	91.4 ± 0.6[a]	92.0 ± 0.4[a]	92.8 ± 0.4[b]	0.30	0.0021
Energy	83.1 ± 0.5[a]	84.5 ± 1.2[b]	87.7 ± 0.8[c]	0.55	0.0001

* Data are the means of five replicates; [2] NFE - nitrogen free extract
[a-c] Means within rows with different superscripts differ at P < 0.05

The effects of cyadox and olaquindox inclusion to the diet on apparent digestibility of mineral elements are shown in Table 6. Pigs fed diets containing cyadox had a higher (P < 0.001) apparent digestibility for calcium and phosphorus than pigs fed the control and olaquindox containing diets. Inclusion of olaquindox increased the apparent digestibility of calcium (P < 0.008) and phosphorus (P < 0.02). Compared with the control, cyadox increased the apparent digestibility of copper (P < 0.001), iron (P < 0.007), zinc (P < 0.001) and manganese (P < 0.004). The apparent digestibility of copper (P < 0.001), iron (P < 0.04) and zinc (P < 0.001) was higher in the cyadox-fed pigs compared with the olaquindox group, but not that of manganese (P > 0.10). Olaquindox increased the apparent digestibility of copper (P < 0.006), zinc (P < 0.09) and manganese (P < 0.03) compared with control, but not that of iron (P > 0.10).

Table 6 Effect of cyadox and olaquindox on the apparent digestibility (%) of mineral elements in the pigs*

Item	Treatments			SEM	Probability
	Control	Olaquindox	Cyadox		
Calcium	55.8 ± 3.0[a]	60.9 ± 2.9[b]	70.1 ± 1.2[c]	1.58	0.0001
Phosphorus	50.4 ± 2.8[a]	56.5 ± 4.9[b]	66.5 ± 2.7[c]	2.30	0.0001
Copper	19.2 ± 3.9[a]	27.8 ± 2.9[b]	43.7 ± 5.1[c]	2.57	0.0001
Iron	18.5 ± 5.6[a]	21.6 ± 6.1[a]	30.2 ± 5.6[b]	3.64	0.0198
Zinc	18.0 ± 4.8[a]	23.8 ± 5.5[a]	38.6 ± 4.2[b]	3.06	0.0001
Manganese	24.1 ± 6.9[a]	35.5 ± 5.4[b]	39.6 ± 8.4[b]	4.42	0.0118

* Data are the means of five replicates per treatment
[a-c] Means within rows with different superscripts differ at P < 0.05

The effects of cyadox and olaquindox inclusion to the diet on the apparent digestibility of amino acids are shown in Table 7. The apparent digestibility of essential and non-essential amino acids was higher (P < 0.01) for pigs fed cyadox than those for pigs fed the control and the olaquindox containing diet. Inclusion of olaquindox increased the apparent digestibility of all the essential amino acids (P < 0.04), and increased the apparent digestibility of aspartic acid (P < 0.006), glutamic acid (P < 0.03), glycine (P < 0.006), cystine (P < 0.001) and tyrosine (P < 0.02).

Table 7 Effects of cyadox and olaquindox on the apparent digestibility (%) of amino acids in the pigs*

Item	Treatments			SEM	Probability
	Control	Olaquindox	Cyadox		
Essential amino acids					
Arginine	92.2 ± 0.5[a]	93.2 ± 0.7[b]	94.3 ± 0.5[c]	0.36	0.0003
Histidine	90.9 ± 0.4[a]	91.9 ± 0.6[b]	93.1 ± 0.6[c]	0.35	0.0002
Isoleucine	77.5 ± 0.4[a]	80.7 ± 2.2[b]	84.1 ± 1.4[c]	0.98	0.0001
Leucine	81.3 ± 0.4[a]	83.3 ± 1.8[b]	86.7 ± 1.1[c]	0.77	0.0001
Lysine	84.5 ± 0.4[a]	86.3 ± 1.1[b]	88.4 ± 1.1[c]	0.58	0.0001
Methionine	78.4 ± 1.3[a]	80.1 ± 1.2[b]	84.1 ± 0.5[c]	0.68	0.0001
Phenylalanine	81.6 ± 0.7[a]	83.3 ± 1.5[b]	86.6 ± 1.1[c]	0.73	0.0001
Threonine	79.1 ± 0.7[a]	81.1 ± 1.5[b]	85.7 ± 0.9[c]	0.69	0.0001
Valine	76.9 ± 0.7[a]	80.1 ± 2.0[b]	83.8 ± 1.3[c]	0.91	0.0001
Non essential amino acids					
Alanine	74.9 ± 0.8[a]	77.0 ± 2.0[a]	81.0 ± 1.7[b]	1.00	0.0002
Aspartic acid	84.1 ± 0.6[a]	85.9 ± 1.2[b]	89.3 ± 0.8[c]	0.56	0.0001
Glutamic acid	85.9 ± 0.3[a]	87.3 ± 1.2[b]	90.7 ± 0.8[c]	0.54	0.0001
Glycine	77.3 ± 0.8[a]	80.2 ± 1.9[b]	84.8 ± 1.3[c]	0.86	0.0001
Cystine	79.7 ± 0.7[a]	82.3 ± 1.1[b]	86.0 ± 0.7[c]	0.53	0.0001
Proline	86.4 ± 0.4[a]	87.2 ± 1.4[a]	89.8 ± 1.0[b]	0.63	0.0004
Serine	85.8 ± 0.9[a]	86.2 ± 0.8[a]	89.7 ± 0.4[b]	0.48	0.0001
Tyrosine	79.3 ± 1.2[a]	81.6 ± 1.7[b]	84.8 ± 0.9[c]	0.83	0.0001

* Data are the means of five replicates per treatment
[a-c] Means within rows with different superscripts differ at $P < 0.05$

Discussion

Weanling pigs fed diets containing antimicrobial agents had greater ADG and FCE than pigs fed unmedicated diets (Hathaway *et al*., 1996; Kendall *et al*., 2000; Weber *et al*., 2001). The present study proved that cyadox and olaquindox had very similar effects. During the 28-day feeding period these products improved daily gain and FCE in piglets significantly. This compares well with previous reports (Broz & Sevcik, 1979; Broz *et al*., 1979; Hamada *et al*., 1988). Some studies suggested that dietary antimicrobials improved daily feed intake and increased body weight gains (Yen & Pond, 1987; 1993). However, cyadox and olaquindox in the present experiment did not affect daily feed intake. It therefore seems as if their growth promoting effects could be the result of increasing absorption and retention of nutrients rather than of increasing feed intake.

According to Visek (1978) and Hernandez *et al*. (2004) antimicrobial agents may increase the absorption and retention of nutrients and decrease nutrients excretion. In agreement with previous reports (Ravindran *et al*., 1984; Decuypere *et al*., 1991; Bartov, 1992; Wuethrich *et al*., 1998), the results of the present study showed that cyadox and olaquindox supplementation increased the digestibility of DM, crude protein, ether extract and NFE. The increased apparent digestibility of dietary energy in cyadox-fed pigs and olaquindox-fed pigs in the current study also agrees with results of previous studies (Buresh *et al*., 1985b; Bartov, 1992; Kirchgessner *et al*., 1995).

In the present study pigs fed medicated diets showed a greater apparent digestibility for calcium and phosphorus than pigs fed the unmedicated diet, which is in agreement with previous reports (Ravindran *et al*., 1984; Buresh *et al*., 1985a). Cyadox increased calcium concentration of breast and thigh muscles in broilers (Tokosova, 1989a), which is in agreement with the present study. Other antimicrobial agents also affected absorption and retention of iron, copper, zinc and manganese, though the effects of different antimicrobial agents were variable: The supplementary olaquindox increased the absorption of iron (Hamada *et al*., 1988). Inclusion of cyadox to broiler diets increased breast muscle copper, but decreased the concentration of manganese in both breast and thigh muscle, and increased feather manganese concentration (Tokosova *et al*., 1989b). In the current study, cyadox significantly increased the apparent digestibility of iron, copper, zinc and manganese. Olaquindox inclusion increased the apparent digestibility of copper, zinc and manganese. However, olaquindox did not affect apparent digestibility of iron, in contrast with a previous report (Hamada *et al*., 1988).

Shafey & McDonald (1991) and Augustine & Danforth (1999) reported that antibiotic supplementation increased the digestibility of amino acids. Olaquindox increased the absorption of amino acids (Hamada *et al*., 1988) and increased the ileal digestibility of lysine, methionine, proline, glycine and alanine (Li *et al*., 2000). Partanen *et al*. (2001) recorded that carbadox supplementation improved the apparent ileal digestibility of several essential and nonessential amino acids in a high-fibre diet. In the present study dietary cyadox supplementation improved the apparent digestibility of the essential and nonessential amino acids. Olaquidox inclusion improved the apparent digestibility of essential amino acids and several nonessential amino acids (alanine, aspartic acid, glutamic acid, glycine, cystine and tyrosine). However, olaquindox did not affect the digestibility of proline and serine.

Conclusion

Under the present experimental conditions cyadox supplementation increased daily gain and FCE in weanling pigs during the 28-day experimental period. Cyadox improved the apparent digestibility of DM, crude protein, ether extract, NFE, energy, essential and nonessential amino acids and calcium, phosphorus, iron, copper, zinc and manganese. It is suggested that the growth-promoting action of cyadox may be related to the increasing of the apparent digestibility of nutrients in pigs.

Acknowledgements

This research was supported by National Natural Science Foundation of China (Project No. 39870596) and Chinese Ministry of Education.

References

AOAC, 2000. Official Methods of Analysis (17th ed.). Association of Official Analytical Chemists, Inc., Gaithersburg, MD, USA.

Augustine, P.C. & Danforth, H.D., 1999. Influence of betaine and salinomycin on intestinal absorption of methionine and glucose and on the ultrastructure of intestinal cells and parasite developmental stages in chicks infected with *Eimeria acervulina*. Avian Dis. 43, 89-97**.**

Bartov, I., 1992. Lack of effect of dietary energy-to-protein ratio and energy concentration on the response of broiler chickens to virginiamycin. Br. Poult. Sci. 33, 381-391.

Broz, J. & Sevcik, B., 1979. Determination of the optimum effective dose of the stimulator cyadox in piglet fattening. Bio. Chem. Zivocisne Vyzoby Vet. 15, 319-325.

Broz, J., Sevcik, B. & Hebky, J., 1979. Growth promoting activity of cyadox in piglet rearing. Z. Tierphysiol. Tierenaehr Futtermittelkd. 41, 237-242.

Buresh, R.E., Miles, R.D. & Harms, R.H., 1985a. Influence of virginiamycin on phosphorus utilization by broiler chicks. Poult. Sci. 64, 757-758.

Buresh, R.E., Miles, R.D. & Harms, R.H., 1985b. Influence of virginiamycin on energy utilization when turkey poults were fed *ad libitum* or restricted. Poult. Sci. 64, 1041-1042.

Chinese Feed Database, 2000. Tables of Feed Composition and Nutritive Value in China (11th ed.). China Feed. 23, 24-29.

Cihak, R. & Srb, V., 1983. Cytogenetic effects of quinoline-1, 4-dioxide- type growth promoting agents. I. Micronucleus test in rats. Mutat. Res. 116, 129-135.

Cihak, R. & Vontorkova, M., 1983. Cytogenetic effects of quinoline-1, 4-dioxide- type growth promoting agents. II. Metaphase analysis in mice. Mutat. Res. 117, 311-316.

Cihak, R. & Vontorkova, M., 1985. Cytogenetic effects of quinoline-1, 4-dioxide-type growth promoting agents. III. Transplacental micronucleus test in mice. Mutat. Res. 114, 81-84.

Consortium, 1988. Guide for the care and use of agricultural animals in agricultural research and teaching. Consortium for Developing a Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching, Champaign, I.L., USA.

Decuypere, J.A., Dierick, N.A., Vervaeke, I.J. & Henderickx, H.K., 1991. Influence of virginiamycin on the digestive physiology in precaecal re-entrant cannulated pigs. Arch. Tierernahr. 41, 373-393.

Graaf, G.J.de & Spierenburg, T.J., 1988. Liquid chromatographic determination of cyadox in medicated feeds and in the contents of the porcine gastrointestinal tract with fluorescence detection. J. Chromatogr. 447, 244-248.

Hamada, H., Maeda, S., Nakayama, E., Hodate, K., Kamada, H., Jimbu, M., Shimbayashi, K. & Kashiwazaki, M., 1988. Effect of supplementing tylosin and olaquindox or copper on growth, tissue mineral contents and enteric bacteria counts of weanling pigs. B. Nat. Inst. Anim. Ind. 47, 59-65.

Hathaway, M.R., Dayton, W.R., White, M.E., Henderson, T.L. & Henningson, T.B., 1996. Serum insulin-like growth factor I (IGF-I) concentrations are increased in pigs fed antimicrobials. J. Anim. Sci. 74, 1541-1547.

Hayes, V.W., 1981. The Hayes Report: Effectiveness of feed additive usage of antibacterial agents in swine and poultry production. Office of Technology Assessment, US Congress, Washington D.C., and Rachelle Laboratories, Long Beach, CA, USA.

Hernandez, F., Madrid, J., Garcia, V., Orengo, J. & Megias, M.D., 2004. Influence of two plant extracts on broilers performance, digestibility, and digestive organ size. Poult Sci. 83, 169-174.

Kendall, D.C., Richert, B.T., Weber, T.E., Bowers, K.A., DeCamp, S.A., Schinckel, A.P. & Matzat, P., 2000. Evaluation of genotype, strategic use of antibiotics and grow-finish management effects on lean growth rate and carcass characteristics. J. Anim. Sci. 78, 39.

Kirchgessner, M., Windisch, W. & Roth, F.X., 1995. Effect of avilamycin and tylosin on the metabolizable energy in growing and finishing pigs. Arch. Tierenahr. 48, 63-70.

Li, T.Z., Zang, S.M. & Li, D.F., 2000. Effect of antibiotic on ileal bacteria populations and nutrients digestibility of fistula pig. Chinese J. Anim. Sci. 36, 21-23.

McCarthy, J.F., Aherne, F.X. & Okai, D.B., 1974. Use of HCl insoluble ash as an index material for determining apparent digestibility with pigs. Can. J. Anim. Sci. 54, 107-109.

NRC, 1998. Nutrient Requirement of Swine. National Academy of Science (9th ed.). National Academic Press, Washington D.C., USA.

Partanen, K., Jalava, T., Valaja, J., Perttilä, S., Silijander-Rasi, H. & Lindeberg, H., 2001. Effect of dietary carbadox of formic acid and fibre level on ileal and faecal nutrient digestibility and microbial metabolite concentrations in ileal digesta of the pig. Anim. Feed Sci. Technol. 93, 137-155.

Ravindran, V., Kornegay, E.T. & Webb, K.E.Jr., 1984. Effect of fiber and virginiamycin on nutrient absorption, nutrient retention and rate of passage in growing swine. J. Anim. Sci. 59, 400-408.

Roof, M.D. & Mahan, D.C., 1982. Effect of carbadox and various dietary copper levels for weanling swine. J. Anim. Sci. 55, 1109-1117.

Roth, F.X. & Kirchgessner, M., 1993. Influence of avilamycin and tylosin on retention and excretion of nitrogen in finishing pigs. J. Anim. Physiol. Anim. Nutri. 69, 245-250.

SAS, 1989. Statistical Analysis Systems user's guide (4th ed.). SAS Institute Inc., Cary, NC., USA.

Shafey, T.M. & McDonald, M.W., 1991. The effects of dietary concentrations of minerals, source of protein, amino acids and antibiotics on the growth of and digestibility of amino acids by broiler chickens. Br. Poult. Sci. 32, 535-544.

Siriwan, P., Bryden, W.L., Molhah, Y. & Annison, E.F., 1993. Measurement of endogenous amino acid losses in poultry. Br. Poult. Sci. 34, 939-949.

Stahly, T.S, Williams, N.H. & Zimmerman, D.R., 1994. Impact of carbadox on rate, efficiency and composition of growth in pigs with low and high level of immune system activation. J. Anim. Sci. 72, Suppl. 1, 165.

Tokosova, M., 1989a. The effect of growth stimulators on the levels of various macroelements in chickens. Vet. Med. (Praha). 34, 51-57.

Tokosova, M., 1989b. The effect of growth stimulators on the levels of various trace elements in chickens. Vet. Med. (Praha). 34, 107-112.

Visek, W.J., 1978. The mode of growth promotion by antibiotics. J. Anim. Sci. 46, 1447-1469.

Weber, T.E., Schinckel, A.P., Houseknecht, K.L. & Richert, B.T., 2001. Evaluation of conjugated linoleic acid and dietary antibiotics as growth promotants in weanling pigs. J. Anim. Sci. 79, 2542-2549.

Wuethrich, A.J., Richardson, L.F., Mowrey, D.H., Paxton, R.E. & Anderson, D.B., 1998. The effect of narasin on apparent nitrogen digestibility and large intestine volatile fatty acid concentrations in finishing swine. J. Anim. Sci. 76, 1056-1063.

Yen, J.T. & Pond, W.G., 1987. Effect of dietary supplementation with vitamin C or carbadox on weanling pigs subjected to crowding stress. J. Anim. Sci. 64, 1672-1681.
Yen, J.T. & Pond, W.G. 1993. Effects of carbadox, copper, or *Yucca shidigera* extract on growth performance and visceral weight of young pigs. J. Anim. Sci. 71, 2140-2146.
Zimmerman, D.R., 1986. Role of subtherapeutic antimicrobials in pig production. J. Anim. Sci. 62, 6-17.