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Effect of virginiamycin on the apparent ileal digestibility of amino acids by growing pigs[1]

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ABSTRACT: The objective of this experiment was to measure the influence of virginiamycin on the apparent ileal digestibility (AID) of AA by growing pigs. Fifteen barrows were surgically equipped with a T-cannula in the distal ileum and used in the experiment (initial BW = 35.0 ± 2.7 kg). Animals were randomly allotted to 3 dietary treatments with 5 pigs per treatment during a 6-wk experiment. Dietary treatments included 1) a basal corn-soybean meal diet, 2) the basal diet supplemented with 11 mg/kg of virginiamycin, and 3) the basal diet supplemented with 22 mg/kg of virginiamycin. Pigs were fed their respective treatment diets during wk 2, 3, and 4, but during wk 1, 5, and 6, all pigs were fed the basal diet. Ileal samples were collected on d 6 and 7 of each week. Results showed that the AID of all indispensable AA, except Arg, His, and Ile, increased ($P < 0.05$) during wk 2, 3, and 4 compared with wk 1 in pigs fed the diet containing 11 mg/kg of virginiamycin. Pigs fed 22 mg/kg of virginiamycin during wk 2, 3, and 4 had increased ($P < 0.05$) AID of Trp and Val during these weeks compared with the AID in wk 1. However, the increased AID of AA did not carry over to wk 5 and 6, when virginiamycin was withdrawn from the diet, regardless of the inclusion rate. In pooled data from wk 2, 3, and 4, the AID of CP, the mean of all indispensable AA, and Ile, Leu, Met, Phe, Trp, and Val increased (linear, $P < 0.05$) as virginiamycin was added to the diets, whereas a tendency ($P < 0.10$) for a linear or quadratic increase was observed for His, Lys, and Thr. These results indicate that addition of virginiamycin to corn-soybean meal diets fed to growing pigs increases the AID of AA, but this effect is not maintained after the removal of virginiamycin from the diet.

Key words: amino acid, ileal digestibility, pig, virginiamycin

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INTRODUCTION

Antimicrobial agents such as virginiamycin have been used in diets fed to swine during the last 5 to 6 decades (Cromwell, 2001). Growth-promoting effects of 11 or 22 mg/kg of virginiamycin have been demonstrated (Jones and Pond, 1963; Pelura et al., 1980; Zimmerman, 1985). Virginiamycin may also increase the digestibility of energy (Vervaeke et al., 1979; Ravindran et al., 1984; Gaines et al., 2005) and P (Agudelo et al., 2007) if included in diets fed to pigs. The effects of virginiamycin on the apparent ileal digestibility (**AID**) of AA in pigs fed a semipurified diet have been determined (Dierick et al., 1986), but to our knowledge, there is no information on the effects of virginiamycin on AA digestibility in corn-soybean meal diets.

Virginiamycin may reduce the concentration of gram-positive bacterial pathogens in the gastrointestinal tract of pigs, which in turn can reduce the production of lactic acid, ammonia, and certain amines in the gastrointestinal tract (Vervaeke et al., 1979; Ravindran et al., 1984; Cromwell, 2001). A reduction in the intestinal concentration of ammonia and amines can reduce the rate of passage of digesta, which may increase the digestibility of nutrients in pigs (Kass et al., 1980; Kim et al., 2007). If a change in intestinal microbial populations is partly responsible for the effects of virginiamycin, it is possible that the effects will persist for a period of time after virginiamycin has been removed from the diet, but we are not aware of any experiments that have tested this hypothesis. Thus, the objective of this experiment was to test the hypothesis that addition of virginiamycin to a corn-soybean meal diet would increase the AID of AA. A second objective was to determine if any effect of virginiamycin on the AID of AA would continue after virginiamycin had been removed from the diet.

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Table 1. Composition of experimental diets (as-fed basis)

	Virginiamycin, mg/kg		
Ingredient, %	0	11	22
Ground corn	67.55	67.55	67.55
Soybean meal, 48% CP	27.50	27.50	27.50
Soybean oil	1.00	1.00	1.00
Cornstarch	1.00	0.95	0.90
Virginiamycin premix[1]	—	0.05	0.10
Ground limestone	1.00	1.00	1.00
Monocalcium phosphate	0.85	0.85	0.85
Chromic oxide	0.40	0.40	0.40
Salt	0.40	0.40	0.40
Vitamin-mineral premix[2]	0.30	0.30	0.30

[1]Contained 22 g of virginiamycin activity per kilogram (virginiamycin premix, Stafac 2.2%, Phibro Animal Health, Ridgefield Park, NJ).

[2]Supplied per kilogram of complete diet: vitamin A, 11,128 IU; vitamin D_3, 2,204 IU; vitamin E, 66 IU; vitamin K, 1.42 mg; thiamine, 0.24 mg; riboflavin, 6.58 mg; pyridoxine, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid, 23.5 mg; niacin, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

MATERIALS AND METHODS

The protocol for the experiment was approved by the Institutional Animal Care and Use Committee of the University of Illinois.

Animals and Housing

The experiment was conducted in an environmentally controlled room at the University of Illinois at Urbana-Champaign. Fifteen growing pigs with an initial BW of 35.0 ± 2.7 kg were surgically equipped with a T-cannula in the distal ileum (Stein et al., 1998). Pigs were the offspring of Line 337 boars mated to C22 females (Pig Improvement Company, Hendersonville, TN). After surgery, pigs were housed individually in 1.2 × 1.8 m metabolism crates. Each crate had a fully slatted expanded metal floor, a stainless steel feeder, and a bowl-type drinker. Pigs were allowed a 7-d recovery period after the surgery before experimental diets were fed, and they had free access to diets and water during the entire experimental period.

Diets, Experimental Design, and Sample Collection

A basal corn-soybean meal diet was formulated (Tables 1 and 2). The diet was formulated to contain 1.0% Lys, which was believed to meet the requirement for pigs growing from 35 to 70 kg. Two additional diets were formulated by adding 0.05 or 0.10% of a virginiamycin premix (Stafac 2.2%, Phibro Animal Health, Ridgefield Park, NJ) to the basal diet at the expense of cornstarch. At these inclusion rates, the diets were supplemented with 11 or 22 mg/kg of virginiamycin. Chromic oxide (0.40%) was included in all diets as an indigestible marker, and vitamins and minerals were included in the diets to meet or exceed current requirement estimates for 20- to 50-kg pigs (NRC, 1998).

Pigs were randomly allotted to 3 treatment groups with 5 pigs per treatment in a completely randomized design. All pigs were fed the basal diet during the first 7-d period (wk 1; Table 3). During the following three 7-d periods (wk 2, 3, and 4), pigs were fed either the basal diet or 1 of the 2 diets containing virginiamycin, but all pigs received the basal diet during the last two 7-d periods (wk 5 and 6). The initial 5 d of each period was a period of adaptation to the diet. Ileal digesta were collected on d 6 and 7 by removing the cap of the cannula and attaching a 225-mL plastic bag to the cannula barrel using a cable tie. Bags were removed whenever they were filled with digesta, or at least once every 30 min, and digesta were collected for 8 h on each of the 2 collection days. All collected samples were immediately stored at −20°C to prevent bacterial degradation of the AA in the digesta.

Chemical Analysis

At the conclusion of the experiment, the frozen ileal samples were allowed to thaw at room temperature and were mixed within animal and collection period, and a subsample was collected for chemical analysis. A sam-

Table 2. Energy and nutrient composition of experimental diets (as-fed basis)[1]

	Virginiamycin, mg/kg		
Item	0	11	22
CP, %	18.43	17.58	17.96
Indispensable AA, %			
Arg	1.22	1.21	1.16
His	0.50	0.49	0.48
Ile	0.80	0.78	0.78
Leu	1.59	1.57	1.54
Lys	1.03	1.01	0.97
Met	0.28	0.29	0.26
Phe	0.92	0.91	0.89
Thr	0.69	0.68	0.64
Trp	0.16	0.20	0.18
Val	0.85	0.85	0.84
Dispensable AA, %			
Ala	0.92	0.90	0.88
Asp	1.85	1.82	1.75
Cys	0.32	0.32	0.33
Glu	3.20	3.16	3.08
Gly	0.77	0.76	0.73
Pro	1.08	1.06	1.04
Ser	0.85	0.82	0.77
Tyr	0.64	0.64	0.61

[1]All diets were formulated to contain 3,305 kcal of ME/kg, 0.63% Ca, 0.55% P, 0.23% relative bioavailable P, and 0.88% standardized ileal digestible Lys. The analyzed concentration of virginiamycin (virginiamycin premix, Stafac 2.2%, Phibro Animal Health, Ridgefield Park, NJ) was <2.0, 11.4, and 19.1 mg/kg for the diets formulated to contain 0, 11, and 22 mg/kg, respectively.

ple of each diet was collected as well. Ileal samples were lyophilized and finely ground before chemical analysis. All samples were analyzed for DM by drying in an oven at 135°C for 2 h (AOAC, 2005; method 930.15) and for CP (AOAC, 2005; method 990.03) using a combustion N analyzer (Rapid N Cube, Elementar Americas Inc., Mt. Laurel, NJ). Concentrations of AA were analyzed using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Before analysis, samples were flushed with N and hydrolyzed with 6 *N* HCl for 24 h at 110°C. Methionine and Cys were analyzed as Met sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis. Tryptophan was determined after alkaline hydrolysis for 22 h at 110°C (AOAC, 2005; method 988.15). The concentrations of Cr in diets and ileal digesta samples were measured using inductively coupled plasma mass spectrometry (AOAC, 2005; method 990.08) after nitric acid-perchloric acid wet ash sample preparation (AOAC, 2005; method 968.088D).

Calculations and Statistical Analysis

The AID values of CP and AA in samples obtained from feeding the experimental diets were calculated as outlined previously (Stein et al., 2007). Data for each treatment group were analyzed using the GLM procedure (SAS Inst. Inc., Cary, NC). The model included period as the independent variable and AID values as response variables within dietary treatment groups. Single degree of freedom contrasts were used to compare effects of virginiamycin within each treatment group (e.g., wk 1 vs. wk 2, 3, and 4; wk 2, 3, and 4 vs. wk 5 and 6; and wk 1 vs. wk 5 and 6). Results for all treatment groups for wk 2, 3, and 4 were analyzed as repeated measures using the MIXED procedure (Littell et al., 1998). Fixed effects included week, dietary treatment, and the interaction between week and treatment. Appropriate covariance structures were chosen based on the Akaike information criterion. Orthogonal polynomial contrasts were used to determine linear and quadratic effects of virginiamycin concentration. The animal was the experimental unit. The α level used for determination of significance among means was 0.05.

RESULTS

Pigs remained healthy throughout the experiment and readily consumed their diets. The ADG of the pigs during the experiment was 778 g and the final BW was 67.7 ± 3.4 kg. The analyzed concentration of Cr in the diets was between 99 and 103% of the expected value.

For pigs fed the basal diet throughout the experiment, the AID for CP and all AA except Glu were not influenced by period (Table 4). For pigs fed the diet containing 11 mg/kg of virginiamycin during wk 2, 3, and 4, the AID of all indispensable AA, except Arg, His, and Ile, and the AID of the mean of the indispensable AA increased ($P < 0.05$) by 2.0 to 6.7 percentage

Table 3. Dietary treatments during the 6-wk experimental period

	Week					
Item	1	2	3	4	5	6
Treatment 1	Basal diet	Basal diet	Basal diet	Basal diet	Basal diet	Basal diet
Treatment 2	Basal diet	Virginiamycin,[1] 11 mg/kg	Virginiamycin, 11 mg/kg	Virginiamycin, 11 mg/kg	Basal diet	Basal diet
Treatment 3	Basal diet	Virginiamycin, 22 mg/kg	Virginiamycin, 22 mg/kg	Virginiamycin, 22 mg/kg	Basal diet	Basal diet

[1]Virginiamycin premix (Stafac 2.2%, Phibro Animal Health, Ridgefield Park, NJ).

Table 4. Effect of feeding period on the apparent ileal digestibility of AA (%) in pigs fed the basal diet for 6 wk[1]

	Week							*P*-value[2]		
Item	1	2	3	4	5	6	SEM	wk 1 vs. wk 2, 3, 4	wk 2, 3, 4 vs. wk 5, 6	wk 1 vs. wk 5, 6
CP	78.5	77.7	76.3	76.6	78.2	78.0	0.9	0.162	0.174	0.755
Indispensable AA										
Arg	88.1	89.2	88.4	87.1	88.0	88.1	0.5	0.819	0.718	0.957
His	82.4	82.5	82.4	81.3	82.7	81.9	0.7	0.721	0.732	0.935
Ile	79.9	79.6	80.9	79.5	80.5	79.4	0.8	0.918	0.939	0.968
Leu	80.3	80.8	81.6	80.7	82.0	80.6	0.9	0.474	0.723	0.350
Lys	81.7	81.8	82.0	80.7	82.0	80.4	1.1	0.884	0.754	0.711
Met	83.0	83.4	82.6	83.2	83.8	83.2	1.0	0.942	0.678	0.706
Phe	80.2	79.7	81.2	80.0	81.2	79.9	0.9	0.915	0.739	0.727
Thr	70.5	71.0	72.8	71.1	72.0	71.8	1.2	0.415	0.795	0.338
Trp	75.6	74.7	72.6	72.3	73.2	71.2	1.6	0.199	0.483	0.088
Val	76.1	75.4	77.2	75.4	76.4	75.4	1.1	0.936	0.887	0.856
Mean	79.8	79.8	80.2	79.1	80.2	79.2	0.9	0.943	0.974	0.927
Dispensable AA										
Ala	74.9	74.3	76.3	75.2	76.3	74.3	1.2	0.743	0.981	0.771
Asp	78.7	76.0	77.5	75.4	77.3	77.4	1.0	0.056	0.276	0.298
Cys	68.8	69.8	68.4	65.6	66.0	70.7	2.0	0.706	0.822	0.850
Glu	80.9	77.1	77.0	75.3	78.2	79.6	1.3	0.009	0.061	0.232
Gly	64.5	61.1	60.0	59.8	62.0	60.1	1.9	0.063	0.661	0.144
Pro	74.9	76.9	75.0	74.7	76.4	78.0	1.9	0.752	0.357	0.327
Ser	79.2	80.0	80.0	78.1	79.5	79.4	1.0	0.876	0.923	0.827
Tyr	79.6	80.1	81.0	79.8	81.1	81.0	0.8	0.471	0.354	0.176
Mean	75.2	74.4	74.4	73.0	74.6	75.1	1.1	0.332	0.380	0.791

[1]Data are means of 5 observations per treatment.
[2]*P*-values are from single degree of freedom contrasts.

units during wk 2, 3, and 4 compared with wk 1 (Table 5). The AID of Ala, Pro, and Tyr also increased ($P < 0.05$) during wk 2, 3, and 4 compared with wk 1, but that was not observed for the remaining dispensable AA. However, the increased AID of AA was not maintained when virginiamycin was withdrawn from the diet, and for all AA except Leu, Glu, and Pro, no difference in the AID was observed between wk 5 and 6 and wk 1.

For pigs fed the diet containing 22 mg/kg of virginiamycin in wk 2, 3, and 4 and the basal diet during the remaining periods, the AID of Trp and Val was greater ($P < 0.05$) in wk 2, 3, and 4 compared with wk 1 (Table 6). The AID of all AA in wk 5 and 6 was not different from the AID in wk 1.

When data for wk 2, 3, and 4 were pooled within each treatment group, no interactions between week and treatments were observed (Table 7). The AID of CP, the mean of all indispensable AA, and the mean of all indispensable AA except Arg, His, Lys, and Thr increased (linear, $P < 0.05$) as the inclusion of virginiamycin in the diet increased from 0 to 11 and 22 mg/kg. A tendency ($P < 0.10$) for a linear increase was observed for His and Thr, and a tendency ($P < 0.10$) for a quadratic increase was observed for Lys as the inclusion of virginiamycin increased from 0 to 11 and 22 mg/kg in the diets. The AID of Ala, Cys, Glu, Pro, and Tyr also increased (linear, $P < 0.05$) as the concentration of virginiamycin increased in the diet. The AID of Arg and Ser decreased ($P < 0.05$) from wk 2 to wk 3 and 4, but the AID of all other AA did not change among wk 2, 3, and 4.

DISCUSSION

In this experiment, period represents both age and BW of the pigs, but over the 6 wk when we fed experimental diets, there were no changes in the AID of AA for pigs fed the basal diet. The digestibility for energy is generally greater in heavier or more mature pigs than in lighter or less mature pigs (Graham et al., 1986; Noblet et al., 1994), but results of this experiment demonstrated that the AID of AA was not influenced by the BW of growing pigs within the BW range of 35 to 67 kg. This observation is in agreement with data showing that the AID of AA in growing pigs is similar to the AID of AA in sows if both groups are allowed ad libitum access to feed (Stein et al., 1999). Kim et al. (2007) also failed to demonstrate a relationship between BW and total tract digestibility of DM in pigs in the BW range of 38 to 72 kg. The fact that there was no period effect on the AID of AA for pigs fed the basal diet indicates that pigs do not change the AID of AA during this period if they are fed the same diet. Any period effects in the AID of AA that were obtained for pigs fed the diets containing virginiamycin can, therefore, be attributed to the presence of virginiamycin in these diets.

Table 5. Effects of feeding period and virginiamycin on the apparent ileal digestibility of AA (%) in pigs fed a corn-soybean meal diet supplemented with 11 mg/kg of virginiamycin in wk 2, 3, and 4 and the basal diet containing no virginiamycin in wk 1, 5, and 6[1]

	Week							*P*-value[2]		
Item	1	2	3	4	5	6	SEM	wk 1 vs. wk 2, 3, 4	wk 2, 3, 4 vs. wk 5, 6	wk 1 vs. wk 5, 6
CP	77.6	80.2	80.5	78.0	77.1	78.4	1.0	0.090	0.050	0.903
Indispensable AA										
Arg	88.2	90.6	88.8	87.8	87.4	88.8	0.5	0.189	0.061	0.848
His	82.6	83.6	84.3	82.6	82.1	83.0	0.8	0.343	0.182	0.912
Ile	79.8	81.7	82.4	81.2	80.9	80.2	0.9	0.052	0.131	0.453
Leu	80.0	83.3	83.4	82.6	82.1	81.9	0.8	0.002	0.116	0.047
Lys	80.9	84.6	84.5	83.3	80.8	81.0	0.8	0.002	0.001	0.996
Met	82.2	85.8	85.6	85.5	84.7	83.2	0.9	0.004	0.051	0.144
Phe	80.4	82.6	82.9	81.6	80.9	80.9	0.8	0.048	0.062	0.616
Thr	70.0	73.4	74.7	72.2	71.3	73.2	1.4	0.039	0.346	0.192
Trp	71.6	77.5	79.5	78.0	72.9	71.4	1.3	0.001	0.001	0.753
Val	75.5	78.4	79.7	77.9	77.0	76.7	1.0	0.015	0.068	0.311
Mean	79.1	82.2	82.6	81.3	80.0	80.0	0.8	0.005	0.013	0.383
Dispensable AA										
Ala	74.3	77.4	78.5	77.0	76.4	76.2	1.0	0.008	0.160	0.108
Asp	78.9	79.3	80.3	77.6	76.8	76.8	1.3	0.895	0.063	0.198
Cys	70.2	71.3	72.5	69.3	68.5	71.1	1.3	0.588	0.336	0.833
Glu	83.0	79.8	81.4	76.9	76.8	77.3	1.8	0.094	0.168	0.012
Gly	62.5	63.9	67.1	60.2	59.4	64.4	2.4	0.647	0.410	0.853
Pro	60.4	77.9	73.9	69.9	70.6	78.4	4.5	0.015	0.883	0.017
Ser	78.8	81.6	80.9	79.0	79.0	80.4	0.9	0.142	0.386	0.447
Tyr	80.0	82.6	83.1	81.5	80.7	81.5	0.8	0.023	0.107	0.306
Mean	73.5	76.7	77.2	73.9	73.5	75.8	1.3	0.110	0.281	0.464

[1]Data are means of 5 observations per treatment (virginiamycin premix, Stafac 2.2%, Phibro Animal Health, Ridgefield Park, NJ).
[2]*P*-values are from single degree of freedom contrasts.

Table 6. Effects of feeding period and virginiamycin on the apparent ileal digestibility of AA (%) in pigs fed a corn-soybean meal diet supplemented with 22 mg/kg of virginiamycin in wk 2, 3, and 4 and the basal diet containing no virginiamycin in wk 1, 5, and 6[1]

	Week							*P*-value[2]		
Item	1	2	3	4	5	6	SEM	wk 1 vs. wk 2, 3, 4	wk 2, 3, 4 vs. wk 5, 6	wk 1 vs. wk 5, 6
CP	77.7	81.0	78.4	77.6	78.3	78.6	1.4	0.401	0.646	0.647
Indispensable AA										
Arg	88.4	90.8	87.2	87.9	87.6	88.1	1.0	0.866	0.380	0.611
His	82.8	84.5	83.3	82.6	83.5	82.4	1.4	0.638	0.638	0.927
Ile	80.6	82.9	82.1	81.5	82.5	80.9	1.2	0.213	0.638	0.399
Leu	81.5	84.3	83.3	82.7	83.8	81.9	1.2	0.122	0.559	0.292
Lys	81.7	85.4	82.5	81.5	83.2	82.2	1.8	0.447	0.790	0.599
Met	84.3	86.8	84.7	84.2	86.4	84.2	1.2	0.447	0.943	0.437
Phe	81.3	83.5	82.4	81.8	82.7	81.1	1.1	0.268	0.450	0.623
Thr	71.8	75.1	73.6	73.1	73.9	73.7	1.6	0.221	0.925	0.272
Trp	73.3	80.4	77.6	79.6	73.4	72.8	1.7	0.003	0.001	0.923
Val	76.4	80.2	80.0	79.1	79.4	78.1	1.5	0.035	0.381	0.160
Mean	80.2	83.4	81.7	81.4	81.6	80.5	1.2	0.138	0.302	0.514
Dispensable AA										
Ala	75.0	79.2	78.1	76.9	78.7	76.7	1.6	0.078	0.797	0.133
Asp	78.5	80.3	77.9	76.4	78.1	77.9	1.7	0.869	0.862	0.773
Cys	69.5	75.7	70.7	71.5	67.9	71.6	2.7	0.275	0.208	0.934
Glu	80.7	82.2	79.2	77.2	78.4	78.3	2.0	0.568	0.468	0.278
Gly	60.6	64.0	62.0	62.1	60.8	64.3	3.3	0.548	0.952	0.598
Pro	59.4	73.0	62.8	68.0	60.9	74.4	7.8	0.310	0.969	0.348
Ser	79.9	82.1	78.9	78.6	80.5	79.5	1.2	0.965	0.897	0.955
Tyr	81.2	83.6	82.2	81.9	82.2	81.4	1.1	0.231	0.382	0.623
Mean	73.1	77.5	74.0	74.1	73.4	75.5	1.7	0.264	0.624	0.482

[1]Data are means of 5 observations per treatment (virginiamycin premix, Stafac 2.2%, Phibro Animal Health, Ridgefield Park, NJ).
[2]*P*-values are from single degree of freedom contrasts.

Table 7. Effects of virginiamycin on the apparent ileal digestibility (%) of AA by pigs fed a corn-soybean meal diet[1]

	Virginiamycin, mg/kg				*P*-value			Week			
Item	0	11	22	SEM	Diet	Linear	Quadratic	2	3	4	*P*-value,[2] week
CP	76.9	79.6	79.0	0.7	0.017	0.033	0.052	79.6	78.4	77.4	0.069
Indispensable AA											
Arg	88.2	89.1	88.6	0.5	0.419	0.555	0.245	90.2	88.1	87.6	<0.001
His	82.1	83.5	83.5	0.6	0.139	0.089	0.316	83.5	83.3	82.2	0.225
Ile	80.0	81.8	82.2	0.6	0.036	0.016	0.368	81.4	81.8	80.7	0.450
Leu	81.0	83.1	83.5	0.6	0.012	0.006	0.233	82.8	82.8	82.0	0.544
Lys	81.5	84.1	83.1	0.8	0.053	0.136	0.056	83.9	83.0	81.8	0.145
Met	83.1	85.6	85.2	0.7	0.015	0.024	0.063	85.4	84.3	84.3	0.396
Phe	80.3	82.4	82.6	0.6	0.014	0.009	0.194	81.9	82.2	81.1	0.412
Thr	71.6	73.4	73.9	0.9	0.131	0.059	0.507	73.2	73.7	72.1	0.397
Trp	73.2	78.3	79.2	1.0	<0.001	<0.001	0.067	77.5	76.5	76.6	0.708
Val	76.0	78.7	79.8	0.8	0.003	0.001	0.410	78.0	79.0	77.5	0.368
Mean	79.7	82.0	82.2	0.6	0.008	0.006	0.146	81.8	81.5	80.6	0.333
Dispensable AA											
Ala	75.3	77.6	78.1	0.7	0.019	0.009	0.283	77.0	77.6	76.4	0.472
Asp	76.3	79.0	78.2	0.9	0.072	0.119	0.093	78.5	78.6	76.5	0.139
Cys	67.9	71.0	72.6	1.2	0.025	0.008	0.597	72.3	70.5	68.8	0.114
Glu	76.5	79.4	79.6	1.1	0.080	0.048	0.296	79.7	79.2	76.5	0.080
Gly	60.3	63.7	62.7	1.5	0.260	0.269	0.233	63.0	63.0	60.7	0.453
Pro	75.6	73.9	67.9	2.5	0.088	0.036	0.478	75.9	70.6	70.9	0.235
Ser	79.4	80.5	79.9	0.6	0.439	0.585	0.252	81.2	80.0	78.5	0.012
Tyr	80.3	82.4	82.6	0.6	0.013	0.008	0.186	82.1	82.1	81.1	0.344
Mean	73.9	75.9	75.2	0.8	0.164	0.245	0.136	76.2	75.2	73.7	0.057

[1]Data are means of 15 observations per treatment (virginiamycin premix Stafac 2.2%, Phibro Animal Health, Ridgefield Park, NJ) or per week.

[2]The interaction between dietary treatment and week was not significant ($P > 0.05$).

The improvement in the AID of most indispensable AA that was observed when virginiamycin was added to the basal diet is in agreement with data showing that the AID of AA is increased if 50 mg/kg of virginiamycin is added to a semipurified diet based on skim milk powder and cornstarch (Dierick et al., 1986). An increase in total tract digestibility of CP was also observed in pigs fed virginiamycin-supplemented diets compared with pigs fed nonsupplemented diets, and the increased digestibility was accompanied by a longer digesta retention time (Ravindran et al., 1984).

Effects of virginiamycin on growth promotion of pigs have been explained by several modes of actions: 1) inhibition of gram-positive bacterial growth, 2) decrease in the decarboxylation and deamination of AA, 3) reduction in the synthesis of lactate and VFA, and 4) a slower rate of digesta passage through the intestinal tract (Cocito, 1979; Dierick et al., 1986; Cromwell, 2001). These actions are all indirectly associated with changes in the intestinal microflora. If bacterial cells are treated with virginiamycin, the bacterial growth is prevented for a prolonged time after removing virginiamycin from the diet, which is called "bacteriopause" (Cocito et al., 1997). However, the results of this experiment indicate that virginiamycin has a rapid digestibility-improving effect and that this effect is not increased over time. We are not aware of any other data that have demonstrated this effect, but the present data indicate that virginiamycin introduces relatively rapid changes in AA digestibility. The AID of all AA returned to the values observed in wk 1 when virginiamycin was removed from the diet, and there was no carryover effect of virginiamycin on the AID of AA. This observation is in agreement with the fact that there is no carryover effect of virginiamycin on growth performance of pigs (Pelura et al., 1980).

Increased absorption of AA from an isolated loop of the small intestine in pigs fed diets containing virginiamycin has been demonstrated (Dierick et al., 1981, 1986), and the absorption of glucose, galactose, Arg, and His in mice was also increased if virginiamycin was included in the diet (Madge, 1969). Virginiamycin may also enhance the activity of some of the enzymes associated with nutrient absorption, including alkaline phosphatase, Na^+-K^+ adenosine triphosphatase, and amino peptidase (Dierick et al., 1981, 1986). These observations indicate that the increase in the AID of AA, which is observed when virginiamycin is included in the diet, is probably modulated directly by virginiamycin.

In conclusion, results of this experiment demonstrated that inclusion of virginiamycin at 11 or 22 mg/kg to a corn-soybean meal diet fed to growing pigs increased the AID of AA. The increase was observed after 1 wk of feeding virginiamycin, and the effect was not maintained when virginiamycin was removed from the diet. Further research is needed to elucidate the mechanisms by which virginiamycin interacts with AA digestibility.

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