Growth Performance of Growing-Finishing Pigs Fed Diets Supplemented with Chinese Cottonseed Meal Based on Amino Acid Digestibilities[a]

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ABSTRACT : Two experiments were conducted to determine the ileal digestibility of the amino acids contained in cottonseed meal using the regression technique and then applying the values obtained, in a growth trial, using growing-finishing pigs. For the digestibility trial, four 20 kg crossbred (Yorkshire × Landrace × Beijing Black) barrows were fitted with simple T-cannula in the terminal ileum. After recovery, the barrows were fed one of four experimental diets according to a 4 × 4 Latin Square design. The pigs were fed corn-soybean meal based diets supplemented with 0, 25, 50 or 75% cottonseed meal. For the growth trial, 128 crossbred (Yorkshire × Landrace × Beijing Black) growing pigs (21 kg) were fed corn-soybean meal diets supplemented with 0, 4, 8 or 12% cottonseed meal. Four pens (4 gilts and 4 castrates) were assigned to each treatment. The digestibility coefficients for the indispensible amino acids declined as the level of cottonseed meal in the diet increased. There was good agreement between the amino acid digestibilities for methionine, threonine and tryptophan determined using the regression technique and amino acid digestibilities previously published for cottonseed meal. However, for lysine, the value of 67% ileal digestibility obtained in the present experiment was higher than most previously published estimates which ranged from 42 to 73%. During both the growing (21-43 kg) and finishing (43-84 kg) periods, the addition of cottonseed meal decreased average daily gain and feed conversion in a linear manner ($p<0.05$). Feed intake was not significantly different between treatments. The overall results suggest that cottonseed meal can be used at levels of up to 8% in diets fed to growing-finishing pigs provided that the diet has been balanced for digestible amino acids. (*Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 4 : 521-527*)

Key Words : Cottonseed Meal, Ileal Digestibility, Amino Acids, Performance, Pigs

INTRODUCTION

Cotton has been grown for several thousands of years as a source of fiber that is used as a textile material (Tanksley, 1990). For every 100 kg of cotton fiber produced, the cotton plant also yields approximately 160 kg of cottonseed. With processing, typical yields from cottonseed are 50% meal, 22% hulls, 16% oil, 7% linters, with a 5% loss. Although much of the meal is utilized in ruminant diets, the price relationship between cottonseed meal and other high-protein feedstuffs often provides an excellant opportunity for pork producers to use cottonseed in order to reduce feed costs (Tanksley, 1990). Over 32 million metric tons of cottonseed were grown worldwide in 1998 (USDA, 1999).

Not all of the amino acids present in feeds are biologically available to the pig. The availability of amino acids can be reduced by incomplete digestion and absorption, by the presence of inhibitors of digestive enzyme or by heat damage (Thacker et al., 1984). Therefore, knowledge of the availability of the individual amino acids in a feed is essential in order to improve the accuracy of diet formulation. The apparent digestibilities of amino acids for pigs have been determined by the ileal and fecal methods (Sauer and de Lange, 1989). The ileal method is considered a more accurate estimate of amino acid availability because it measures digestibility prior to microbial degradation and synthesis of amino acids in the large intestine (Knabe et al., 1989).

The determination of ileal digestibility coefficients for amino acids is usually conducted using the direct method (e.g., Knabe et al., 1989; Herkelman et al., 1992). However, a regression technique has recently been proposed as an alternative method for measuring ileal digestibility (Fan and Sauer, 1995a, b; Fan et al., 1995). Since this technique has not been applied to cottonseed meal, an experiment was conducted to determine the ileal digestibility of amino acids in cottonseed meal using the regression technique and then to apply the values obtained, in a growth trial, to determine the performance of growing-finishing pigs fed diets formulated on an ileal digestible amino acid basis.

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Table 1. Ingredient composition of diets fed to determine the ileal digestibility of amino acids in cottonseed meal when fed to growing pigs

	Basal diet	75% Basal+25% Cottonseed meal	50% Basal+50% Cottonseed meal	50% Basal+50% Cottonseed meal
Ingredients (%, as fed)				
Corn	71.74	53.37	34.77	16.17
Soybean meal	23.98	17.79	11.59	5.36
Cottonseed meal	-	25.00	50.00	75.00
Limestone	0.80	0.80	0.90	1.00
Dicalcium phosphate	1.75	1.45	1.15	0.85
Salt	0.34	0.34	0.34	0.34
L-lysine HCl	0.14	-	-	-
Premix[1]	1.00	1.00	1.00	1.00
Chromic oxide	0.25	0.25	0.25	0.25

[1] Supplied per kilogram of diet: 5,512 IU vitamin A; 551 IU vitamin D_3; 66 IU vitamin E; 2.2 mg vitamin K_3; 5.5 mg riboflavin; 13.8 mg pantothenic acid; 30.3 mg niacin; 551 mg choline; 27.6 μg vitamin B_{12}; 30 mg Mn; 100 mg Fe; 100 mg Zn; 10 mg Cu; 0.5 mg I; 1 mg Co; 0.3 mg Se; 50 mg olaquindox; 8 mg antioxidant.

Table 2. Chemical composition of cottonseed meal and the experimental diets used to determine the ileal digestibility of amino acids in cottonseed meal[1]

	Cottonseed meal	Basal diet	75% Basal+25% Cottonseed meal	50% Basal+50% Cottonseed meal	50% Basal+50% Cottonseed meal
Chemical analysis (%, as fed)					
Crude protein	42.35	16.54	22.82	28.89	35.43
Crude fiber	10.28	2.31	4.27	6.26	8.24
Ether extract	0.73	3.55	2.42	1.83	1.21
Calcium	0.25	0.75	0.73	0.74	0.73
Total phosphorus	0.97	0.63	0.72	0.81	0.92
Indispensible amino acids (%, as fed)					
Arginine	4.24	1.12	1.87	2.93	3.41
Histidine	1.05	0.45	0.59	0.74	0.88
Isoleucine	1.26	0.63	0.78	0.93	1.07
Leucine	2.31	1.54	1.69	1.81	2.05
Lysine	1.57	0.96	1.01	1.18	1.35
Methionine+cystine	1.23	0.57	0.72	0.88	1.04
Phenylalanine	2.18	0.85	1.18	1.49	1.83
Threonine	1.19	0.66	0.77	0.91	1.02
Tryptophan	0.41	0.19	0.22	0.28	0.35
Valine	1.74	0.76	0.98	1.23	1.43

[1] Each value represents the mean of chemical analysis conducted in duplicate.

MATERIALS AND METHODS

Digestibility trial

Four crossbred (Yorkshire × Landrace × Beijing Black) barrows, weighing 20 ± 0.5 kg, were fitted with simple T-cannula in the terminal ileum (12 to 15 cm anterior to the ileocecal junction). The nylon T-cannula, with a threaded 1.2 cm outside diameter tube and curved T-flange 6 cm long, were prepared at the Beijing Agricultural University Machine Shop from nylon rod stock purchased locally. A detailed description of the procedures used to install the cannulas was published previously (Zhu et al., 1998). The pigs were allowed a 10 day recuperation period before starting the experiment during which they were fed a standard corn-soybean meal based diet.

After recovery, the barrows were fed one of four experimental diets (table 1) according to a 4 × 4 Latin Square design. Each test period lasted 12 days, consisting of a 10 day adjustment to the diet followed by a 2 day collection of ileal digesta. The basal diet was based on corn and soybean meal and was supplemented with sufficient lysine, vitamins and minerals to meet or exceed published requirements for pigs between 20 and 50 kg (NRC, 1998; table 2). For the three test diets, increasing amounts of corn and soybean meal were removed from the diet and replaced with either 25, 50 or 75% cottonseed meal.

Chromic oxide (0.25%) was added to all of the diets as a digestibility marker.

Throughout the experiment, the barrows were individually housed in 0.5 m×1.5 m cast iron metabolic crates equipped with a 0.25 m^3 round bottom feeder located at the front of the crate. The crates were located in an environmentally controlled barn with the temperature set at 20℃. The barrows were fed at 0800 h and 2000 h each day. Feed intake was maintained at a constant level for all pigs during each experimental period. The amount fed was the amount consumed by the pig eating the least during the first 3 days of adjustment phase. Water was added to the diets prior to feeding to form a moist, crumbly mixture and the barrows typically consumed their ration within 30 minutes of feeding.

Collection of ileal digesta started one hour after the morning feeding on day 11 of each test period. The cannula were opened and a soft rubber tube was attached to the barrel of the cannula. The opposite end of the tube was inserted into a plastic bottle surrounded by crushed ice. Digesta was collected for three 12 h periods with a 2 h break between each collection. A 200 ml aliquot from each collection was placed in a freezer and stored at -20℃. The remainder of the chyme was warmed and put back into the ileum through the cannula. At the completion of the third collection, the two frozen digesta samples were thawed and mixed with the third collection and 200 ml of the mixed sample was frozen again and stored at -20℃. Prior to analysis, the digesta was thawed, freeze dried, then ground through a 1 mm screen.

Growth trial

The growth trial was conducted at the Xianyang Swine Breeding Farm located in Henan Provice in the Peoples Republic of China. For the growth trial, 128 crossbred (Yorkshire×Landrace×Beijing Black) growing pigs, weighing 21 kg were allotted into 4 treatment groups on the basis of sex, weight and litter. The four test diets were based on corn and soybean meal and were supplemented with either 0, 4, 8, or 12% cottonseed meal, added largely at the expense of the soybean meal. The digestibility coefficients for lysine and the sulfur containing amino acids, which were calculated based on the results of the digestibility trial, were used in the ration formulation matrix so that all diets provided equal levels of digestible lysine and the sulfur containing amino acids.

The experiment was partitioned into two phases. During the growing phase, lasting 42 days, the diets were formulated to provide 16% crude protein, 0.72% digestible lysine and 0.52% digestible sulfur containing amino acids. During the finishing phase, lasting 63 days, the diets were formulated to provide 14.1% crude protein, 0.64% digestible lysine and 0.47% digestible sulfur amino acids (table 3). All diets were provided in mash form and contained sufficient

Table 3. Composition of diets fed to determine the effect of different levels of cottonseed meal on the performance of growing (21~43 kg) and finishing pigs (43~84 kg)

	Grower				Finisher			
	0	4	8	12	0	4	8	12
Ingredients (%, as fed)								
Corn	73.89	73.20	72.91	72.53	78.79	78.81	78.54	78.46
Soybean meal	22.05	18.70	14.90	11.30	13.40	13.40	9.60	5.60
Cottonseed meal	0.00	4.00	8.00	12.00	0.00	4.00	8.00	12.00
Dicalcium phosphate	2.00	1.90	1.85	1.76	1.80	1.72	1.65	1.57
Limestone	0.65	0.73	0.79	0.80	0.50	0.58	0.65	0.73
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin-mineral premix[1]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Lysine-HCl	0.06	0.11	0.18	0.23	0.08	0.15	0.21	0.27
DL-methionine	0.05	0.06	0.07	0.08	0.03	0.04	0.05	0.07
Total	100	100	100	100	100	100	100	100
Chemical analysis (%, as fed)[2]								
Crude protein	15.86	16.03	15.94	16.09	14.19	14.13	14.01	14.07
Total lysine	0.86	0.86	0.87	0.88	0.76	0.75	0.74	0.76
Total sulfur amino acids	0.60	0.59	0.61	0.62	0.55	0.55	0.54	0.57
Digestible lysine	0.72	0.72	0.72	0.72	0.64	0.64	0.64	0.64
Digestible sulfur amino acids	0.52	0.52	0.52	0.52	0.47	0.47	0.47	0.47
Calcium	0.75	0.76	0.76	0.78	0.66	0.66	0.66	0.66
Phosphorus	0.66	0.67	0.67	0.68	0.60	0.61	0.63	0.62

[1] Supplied per kilogram of diet: 5,512 IU vitamin A; 551 IU vitamin D_3; 66 IU vitamin E; 2.2 mg vitamin K_3; 5.5 mg riboflavin; 13.8 mg pantothenic acid; 30.3 mg niacin; 551 mg choline; 27.6 μg vitamin B_{12}; 100 mg Mn; 100 mg Fe; 100 mg Zn; 10 mg Cu; 0.5 mg I; 1 mg Co; 0.3 mg Se; 50 mg olaquindox; 8 mg antioxidant.

[2] Each value represents the mean of a chemical analysis conducted in duplicate.

vitamins and minerals to meet or exceed NRC (1998) requirements.

All pigs were housed in groups of 8, in an environmentally controlled building containing concrete-floored, partially-slatted pens equipped with self feeders. The pen size during the grower phase was 2.8 m × 3.9 m while during the finishing phase, 3.2 m × 4.5 m pens were used. Four pens, containing 4 gilts and 4 castrates were assigned to each treatment. Pigs were permitted *ad libitum* access to feed and water throughout the experiment. Pigs were weighed individually at the initiation and completion of the growing and finishing phases. Feed consumption was recorded on a pen basis and used to calculate feed conversion at the completion of the trial.

Chemical analysis

Samples of all feeds were analyzed for their nitrogen, calcium and total phosphorus content using the methods of the AOAC (1990). Nitrogen was analyzed using the Kjeldahl method (AOAC method 988.05), calcium by titration with 0.1 N $KMnO_4$ (AOAC method 927.02) and total phosphorus was determined colorimetrically using a molybodovanadate reagent (AOAC method 965.17). Chromic oxide was conducted according to the description provided by Christian and Coup (1954).

Samples of both digesta and diets were hydrolyzed with 6 M HCl at 110℃ for 24 h and analyzed for their amino acid content using high-performance liquid chromatography (Shimadzu LC 10 Liquid Chromograph, Kyoto, Japan). Methionine was determined using formic acid (9 parts of 88% formic acid plus 1 part 30% hydrogen peroxide) protection before acid hydrolysis. Tryptophan was determined following sodium hydroxide (4.2 N NaOH) hydrolysis (20 hr at 110℃). The apparent ileal digestibility of amino acids was calculated based on the relative concentration of chromic oxide in the diet and ileal digesta. Gossypol was determined by the method of Yi (1987).

Statistical Analysis

A linear least squares regression analysis was conducted using SAS (1989) to produce the best fit, linear regression equation between apparent ileal digestibility of each amino acid (Y) and the replacement level of cottonseed meal (x) using the model of Y=bx+c. The apparent ileal digestibility of the amino acids in cottonseed meal was achieved by the extrapolation of this equation to a diet where cottonseed meal consisted of 100% of the tested feedstuff (i.e., x=1).

For the growth trial, the GLM procedures of SAS (1989) were used to determine treatment effects using a one way analysis of variance. Polynomial contrasts (linear, quadratic and cubic) were used to test the effect of cottonseed meal level on the various parameters measured (SAS, 1989).

RESULTS AND DISCUSSION

The results of the chemical analysis conducted on the cottonseed meal used in the present study are presented in table 2. The cottonseed meal used had 42.35% crude protein, 10.28% crude fiber, 0.73% ether extract, 0.25% calcium and 0.97% phosphorus. These findings are similar to the results of chemical analyses published for cottonseed meal by the NRC (1998), Tanksley (1990), Aherne and Kennelly (1982), Knabe et al. (1989), Prawirodigdo et al. (1997), Rhone Poulenc (1993) and Papadopoulos and Ziras (1987). In addition, the concentrations of the indispensible amino acids for the cottonseed meal used in the present study were similar to those presented in the publications listed above.

The ileal digestibility of the amino acids in the diets containing graded levels of cottonseed meal are shown in table 4. The digestibility coefficients for all the indispensible amino acids declined as the level of cottonseed meal in the diet increased.

The regression equations generated from the ileal

Table 4. Apparent ileal amino acid digestibility of diets containing various levels of cottonseed meal

	Basal diet	75% Basal+25% Cottonseed meal	50% Basal+50% Cottonseed meal	25% Basal+75% Cottonseed meal	SEM[1]
Arginine[2]	93.25	89.66	89.53	87.95	1.7
Histidine	80.36	73.42	73.06	69.85	3.3
Isoleucine	75.97	72.62	69.89	65.22	3.8
Leucine	80.41	79.21	76.61	73.49	1.5
Lysine	78.63	76.45	71.99	70.97	2.7
Methionine	81.29	78.90	77.40	75.22	1.6
Phenylalanine	80.77	76.30	74.08	74.30	2.7
Threonine	77.29	73.44	71.30	68.12	2.4
Tryptophan	76.61	74.77	69.03	72.26	3.2
Valine	74.52	70.32	63.19	60.70	4.6

[1] Standard error of the mean.

[2] Each value represents the mean of the analysis from four digesta samples conducted in duplicate.

Table 5. Regression equations to determine the apparent ileal digestibility of the amino acids in cottonseed meal

Amino acids	Regression equations[1]	R^2	Cottonseed meal digestibility
Arginine	Y= -6.41x + 91.50	0.85	85.09
Histidine	Y=-12.76x + 78.96	0.87	66.20
Isoleucine	Y=-13.99x + 76.17	0.96	62.18
Leucine	Y= -9.34x + 80.93	0.97	71.60
Lysine	Y=-10.98x + 78.63	0.95	67.65
Methionine	Y= -7.88x + 81.16	0.96	73.28
Phenylalanine	Y= -8.65x + 79.61	0.81	70.69
Threonine	Y= -9.62x + 73.25	0.92	63.63
Tryptophan	Y= -7.52x + 75.99	0.55	68.47
Valine	Y=-19.44x + 74.47	0.97	55.03

[1] Y=apparent ileal digestibility of an amino acid, x= replacement level of cottonseed meal.

Table 6. The apparent ileal digestibility (%) of amino acids in cottonseed meal determined with the regression technique compared with previously published values

	Current Regression Method	NRC (1998)	Heartland Lysine (1988)	Yin et al. (1994)	Rhone Poulenc (1993)	Batteham et al. (1990)	Knabe et al. (1989)	Tanksley et al. (1981)
Arginine	85	88	87	86	87	89	87	87
Histidine	66	77	74	62	76	91	66	79
Isoleucine	62	69	68	66	66	81	60	66
Leucine	71	70	69	68	68	82	66	69
Lysine	67	61	59	43	59	73	42	62
Methionine	73	73	71	64	71	87	-	65
Phenylalanine	70	81	79	77	79	87	81	76
Threonine	63	61	61	67	61	73	56	62
Tryptophan	68	59	68	-	59	-	71	69
Valine	55	67	70	65	67	81	68	68

digestibility data and the digestibility coefficients obtained when the equation was extrapolated to 100% cottonseed meal are shown in table 5. These values are compared with previously published estimates of cottonseed meal amino acid digestibility in table 6 (Heartland Lysine, 1998; NRC, 1998; Yin et al., 1994; Rhone Poulenc, 1993; Knabe et al., 1989; Tanksley et al., 1981; Batterham et al., 1990). For the amino acids most likely to be limiting in cereal grains (i.e., lysine, methionine, threonine and tryptophan: Sauer et al., 1977), the results from the current experiment showed good agreement with previously published values and differed by 5 or less percentage units for all these amino acids except lysine. For lysine, the value of 67% ileal digestibility obtained in the present experiment was higher than most previously published estimates which ranged from 42 to 73%. In addition, the ileal digestibility of valine differed by 10 or more percentage units when compared with previously published values.

During the both the growing (21-43 kg) and finishing (43-84 kg) and over the entire experiment (21-84 kg), average daily gain declined in a linear manner ($p<0.05$) with increasing amounts of cottonseed meal (table 7). Feed intake was not significantly altered while feed conversion also declined in a linear manner ($p<0.05$). For both gain and feed conversion, the decline was most noticeable at the 12% level of inclusion with pigs fed this treatment gaining weight 18.6% slower than the controls with a feed conversion 14.4% poorer.

The results of the present trial are consistent with other research which have shown that use of cottonseed as a source of protein-rich feed in the diet of growing-finishing pigs results in poorer pig performance (Haines et al., 1957; LaRue et al., 1985; Papadopoulos et al., 1987; Balogun et al., 1990). One of the principle reasons suggested for the poor performance of pigs fed cottonseed meal is its low protein quality, especially its low lysine content (Papadopoulos et al., 1987). Supplementation of diets with synthetic amino acids such as lysine (Hale and

Table 7. Effect of graded levels of cottonseed meal on the performance of growing-finishing pigs

	Level of cottonseed meal (%)				SEM[2]	Polynomial contrast[1]		
	0	5	10	15		L	Q	C
Growing period (21~43 kg)								
Average daily gain (kg)	0.55	0.53	0.53	0.41	0.012	0.001	NS	NS
Average daily feed (kg)	1.44	1.47	1.48	1.27	0.023	0.12	NS	NS
Feed conversion	2.62	2.76	2.80	3.11	0.031	0.04	NS	NS
Finishing period (43~84 kg)								
Average daily gain (kg)	0.62	0.62	0.61	0.51	0.015	0.04	NS	NS
Average daily feed (kg)	2.16	2.18	2.17	2.04	0.031	0.11	NS	NS
Feed conversion	3.49	3.52	3.57	4.03	0.034	0.03	NS	NS
Entire period (21 to 84 kg)								
Average daily gain (kg)	0.59	0.58	0.57	0.48	0.090	0.04	NS	NS
Average daily feed (kg)	1.89	1.86	1.91	1.75	0.025	0.09	NS	NS
Feed conversion	3.19	3.20	3.35	3.65	0.033	0.02	NS	NS

[1] NS=nonsignificant; [2] SEM=Standard error of the mean.

Lyman, 1961; Bell and Larson, 1963; Hintz and Heitman, 1967) and methionine (Miner et al., 1955) have improved weight gain and feed conversion but generally not to the level obtained with soybean meal.

Since the diets used in the present experiment were formulated to supply equal levels of digestible lysine and the sulfur amino acids, it is unlikely that an amino acid deficiency can completely account for the failure of cottonseed meal to support pig growth at a similar level as was obtained with soybean meal.

However, Prawirodigdo et al. (1997) suggested that although the amino acids in cottonseed are digested, some are absorbed in a form that cannot be utilized by the pig.

In addition, cottonseed meal has other nutritional limitations that may account for the poorer performance of pigs fed high levels of cottonseed meal. These are a high crude fiber level and a high gossypol content (LaRue et al., 1985). The higher crude fiber content of cottonseed meal would lower the energy level of the diet which would result in slower growth rates.

The gossypol content of the cottonseed meal used was 0.32%. At the higher levels of cottonseed meal inclusion, the gossypol content of the diet would exceed 100 mg/kg which is the concentration of gossypol at which feed consumption and daily gains have been shown to be decreased (Hale and Lyman, 1957; Tanksley, 1990).

IMPLICATIONS

There was good agreement between the amino acid digestibilities for methionine, threonine and tryptophan determined using the regression technique and amino acid digestibilities previously published for cottonseed meal. For lysine, the value of 67% ileal digestibility obtained in the present experiment was higher than most previously published estimates which ranged from 42 to 73%. These amino acid digestibility values were then applied in a growth trial to determine the performance of growing-finishing pigs fed graded levels of cottonseed meal in diets formulated on an ileal digestible amino acid basis. The overall results suggest that cottonseed meal can be used at levels up to 8% in diets fed to growing-finishing pigs provided that the diet has been balanced for digestible amino acids.

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