Nutritional Evaluation of Chinese Nonconventional Protein Feedstuffs for Growing-Finishing Pigs - 1. Linseed Meal*

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ABSTRACT : Two experiments were conducted to determine the ileal digestibility of the amino acids contained in linseed 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±0.5 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% linseed meal. For the growth trial, 80 crossbred (Yorkshire×Landrace×Beijing Black) growing pigs (20.2±1.5 kg) were fed corn-soybean meal diets supplemented with 0, 5, 10 or 15% linseed meal. Five pens (2 gilts and 2 castrates) were assigned to each treatment. With the exception of leucine, the digestibility coefficients for the indispensible amino acids declined as the level of linseed meal in the diet increased. There was a good agreement between the amino acid digestibilities for lysine, methionine, threonine and tryptophan determined using the regression technique and amino acid digestibilities previously published for linseed meal. During both the growing (20-49 kg) and finishing (49-95 kg) periods, the addition of linseed meal decreased average daily gain and feed conversion in a linear manner ($p<0.05$). Feed intake was not significantly different among treatments. The overall results suggest that linseed meal can be used at levels of between 5 and 10% 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. 1 : 39-45)*

Key Words : Linseed Meal, Ileal Digestibility, Amino Acids, Growing-Finishing Pigs

INTRODUCTION

Linseed (*Linum simun ustiatis*) is one of the oldest crops known to man (Aherne and Kennelly, 1982). World production of linseed has remained virtually constant over the past 50 years varying from 2.6 to 3.3 million tonnes per year (Prentice, 1989). However, since the demand for other oilseeds has increased significantly, the importance of linseed relative to other crops has declined (Bowland, 1990).

Linseed meal is a protein-rich by-product produced during the extraction of oil from linseed or flax. It is intermediate in protein content when compared with other oilseed meals, averaging 36% (Bowland, 1990). However, the meal is low in the amino acid lysine which seriously limits its potential for use as a protein supplement in rations fed to swine (Pond and Maner, 1984).

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 linseed meal, an experiment was conducted to determine the ileal digestibility of amino acids in linseed 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.

MATERIALS AND METHODS

Digestibility trial

Four crossbred (Yorkshire×Landrace×Beijing Black)

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* This project was partially supported by the BASF Korea Ltd. and China Natural Science Foundation.
Received July 6, 1999; Accepted October 23, 1999

Table 1. Ingrediet composition of diets fed to determine the ileal digestibilty of amino acids in linseed meal for growing pigs

	Basal diet	75% Basal+25% Linseed meal	50% Basal+50% Linseed meal	25% Basal+75% Linseed meal
Ingredients (%, as fed)				
Corn	71.74	53.37	34.85	16.32
Soybean meal	23.98	17.79	11.61	5.44
Linseed meal	-	25.00	50.00	75.00
Limestone	0.80	0.80	0.80	0.80
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 viamin E; 2.2 mg vitamin K_3; 5.5 mg riboflvin; 13.8 mg pantothenic acid; 30.3 mg niacin; 551 mg choline; 27.6 μg vitamin B_{12}; 30 mg Mn; 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 linseed meal and the experimental diets used to determine the ileal digestibility of amino acids in linseed meal[1]

	Linseed meal	Basal diet	75% Basal+25% Linseed meal	50% Basal+50% Linseed meal	25% Basal+75% Linseed meal
Chemical analysis (%, as fed)					
Crude protein	34.56	16.24	20.96	25.08	26.29
Crude fiber	8.28	2.37	3.81	5.27	6.70
Ether extract	1.79	3.03	2.65	2.37	2.01
Calcium	0.41	0.75	0.77	0.77	0.79
Total phosphorus	0.95	0.64	0.73	0.82	0.92
Indispensible amino acids (%, as fed)					
Arginine	3.57	1.14	1.74	2.30	2.91
Histidine	0.64	0.47	0.49	0.53	0.59
Isoleucin	1.32	0.63	0.78	0.94	1.11
Leucin	1.83	1.49	1.57	1.65	1.70
Lysine	1.17	0.95	0.93	1.01	1.05
Methionine+cystine	1.08	0.54	0.68	0.81	0.93
Phenylalanine	1.55	0.86	1.04	1.18	1.35
Threonine	1.14	0.66	0.75	0.89	1.01
Tryptophan	0.66	0.19	0.30	0.42	0.51
Valine	1.49	0.77	0.93	1.12	1.28

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

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% linseed 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 0.5×1.5 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, freezedried, then ground through a 1 mm screen.

Growth trial

For a growth trial, 80 crossbred (Yorkshire×Landrace×Beijing Black) growing pigs, weighing 20.2 ±1.5 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, 5, 10 or 15% linseed meal, added largely at the expense of the soybean meal (table 3). 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, 0.77% digestible lysine and 0.54% digestible sulfur containing amino acids. During the finishing phase lasting 60

Table 3. Composition of diets fed to determine the effect of different levels of linseed meal on the performance of growing-finishing pigs

	Growth				Finisher			
	0	5	10	15	0	5	10	15
Ingredients (%, as fed)								
Corn	72.55	71.03	69.38	68.99	77.34	75.73	74.14	72.47
Soybean meal	23.40	19.90	16.50	11.80	18.90	45.50	12.00	8.60
Linseed meal	0.00	5.00	10.00	15.00	0.00	5.00	10.00	15.00
Limestone	0.68	0.68	0.70	0.75	0.70	0.70	0.75	0.80
Salt	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Lysine-HCl	0.08	0.15	0.22	0.30	0.09	0.15	0.23	0.30
DL-methionine	0.05	0.05	0.06	0.07	0.03	0.03	0.04	0.04
Dicalcium phosphate	1.90	1.85	1.80	1.75	1.60	1.55	1.50	1.45
Vitamin-mineral premix[1]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Chemical analysis (%, as fed)[2]								
Crude protein	16.12	16.05	16.11	16.09	15.13	15.00	15.11	15.15
Calcium	0.75	0.77	0.76	0.78	0.68	0.69	0.70	0.72
Phosphorus	0.66	0.65	0.67	0.68	0.59	0.60	0.62	0.64
Total lysine	0.91	0.92	0.91	0.93	0.81	0.79	0.81	0.83
Total sulfur amino acids	0.62	0.62	0.61	0.63	0.53	0.53	0.54	0.55
Digestible lysine	0.77	0.77	0.77	0.77	0.68	0.68	0.68	0.68
Digestible sulfur amino acids	0.54	0.54	0.54	0.54	0.45	0.45	0.45	0.45

[1] Supplied per kilogram of diet: 5,512 IU vitamin A; 551 IU vitamin D_3; 66.1 IU vitamin E; 2.2 mg vitamin K_3; 0.8 mg thiamine; 5.50 mg riboflvin; 13.80 mg pantothenic acid; 30.3 mg niacin; 600 mg choline; 27.6 μg vitamin B_{12}; 10 mg Mn; 9 mg Fe; 50 mg Zn; 120 mg Cu; 30 mg Co; 0.3 mg Se; 3.32 mg I; 1.00 mg carbadox; 120 mg ethoxyquin (as antioxidant).

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

days, the diets were formulated to provide 15% crude protein, 0.68% digestible lysine and 0.45% digestible sulfur amino acids. All diets were provided in mash form and contained sufficient vitamins and minerals to meet or exceed NRC (1998) requirements.

All pigs were housed in groups of 4, in an environmentally controlled building containing 1.2×2.0 m concrete-floored, partially-slatted pens equipped with self feeders. Five pens, containing 2 gilts and 2 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 by atomic absorption (Hitachi Z-5000, Japan) according to the description provided by Christian and Coup (1954). Samples of both digesta and diets were hydrolyzed with 6 mol/l 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.

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 linseed meal (x) using the model of Y=bx+c. The apparent ileal digestibility of the amino acids in linseed meal was achieved by the extrapolation of this equation to a diet where linseed 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 linseed meal level on the various parameters measured (SAS, 1989).

RESULTS AND DISCUSSION

The results of the chemical analysis conducted on the linseed meal used in the present study are presented in table 2. The linseed meal used had 34.6% crude protein, 8.28% crude fiber, 1.79% ether extract, 0.41% calcium and 0.95% phosphorus. These findings are similar to the results of chemical analyses published for linseed meal by Aherne and Kenelly (1982), Bowland (1990) and. NRC (1998). In addition, the concentrations of the indispensible amino acids for the linseed meal used in the present study were similar to those presented in the publications listed above.

The ileal digestibilities of the amino acids in the diets containing graded levels of linseed meal are shown in table 4. With the exception of leucine, the digestibility coefficients for all the indispensible amino

Table 4. Ileal amino digestibility of diets containing various levels of linseed meal

	Basal diet	75% Basal+25% Linseed meal	50% Basal+50% Linseed meal	25% Basal+75% Linseed meal	SEM[1]
Arginine	88.95	84.82	79.74	75.36	3.7
Histidine	82.98	76.24	73.60	69.36	9.7
Isoleucin	78.98	81.68	80.23	83.95	1.1
Leucin	73.93	78.91	78.67	79.62	2.1
Lysine	89.59	78.56	81.48	76.38	4.6
Methionine	84.45	82.25	83.11	79.84	3.8
Phenylalanine	85.12	83.61	80.11	81.67	2.0
Threonine	67.06	72.56	65.60	63.09	6.3
Tryptophan	88.80	81.56	81.37	76.89	1.0
Valine	78.56	75.61	75.57	69.24	1.4

[1] Standard Error of the Mean.
[2] Each value represents the mean of the analysis from four digesta Samples conducted in duplicate.

acids declined as the level of linseed meal in the diet increased.

The regression equations generated from the ileal digestibility data and the digestibility coefficients obtained when the equation was extrapolated to 100% linseed meal are shown in table 5. These values are compared with previously published estimates of linseed meal amino acid digestibility in table 6 (Heartland Lysine, 1998; NRC, 1998). 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 differed from previously published values by 5 or less percentage units. However, the results of the present experiment differed by 10 or more percentage units for arginine, isoleucine and leucine when compared with previously published values.

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

Amino acids	Regression equations[1]	R^2	Linseed digestibility
Arginine	Y=-18.34x+89.10	0.90	70.75
Histidine	Y=-12.60x+78.27	0.81	65.67
Isoleucine	Y=5.38x+79.19	0.66	84.58
Leucine	Y=6.73x+75.26	0.70	81.99
Lysine	Y=-14.68x+87.01	0.67	72.33
Methionine	Y=9.81x+82.36	0.81	72.55
Phenylalanine	Y=-7.46x+85.71	0.95	77.65
Threonine	Y=-6.85x+67.01	0.81	60.16
Tryptophan	Y=-13.03x+83.14	0.93	70.11
Valine	Y=-11.20x+78.95	0.85	67.75

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

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

	Current regression method	Heartland Lysine (1988)	NRC (1998)
Arginine	71	86	86
Histidine	66	72	72
Isoleucine	85	75	75
Leucine	82	68	68
Lysine	72	70	70
Methionine	73	76	76
Phenylalanine	78	78	78
Threonine	60	63	63
Tryptophan	70	75	75
Valine	68	74	74

The effects of including graded levels of linseed meal on the performance of growing-finishing pigs are shown in table 7. During the growing (20-49 kg) period, there was a linear decline (p=0.03) in growth rate as the level of linseed meal in the diet increased. This decline was most apparent at the 15% inclusion level. Feed intake showed a trend (p=0.09) to decrease with increasing levels of linseed meal while feed conversion also declined (p=0.05) with linseed meal inclusion.

During the finishing period (49-95 kg), the addition of linseed meal decreased average daily gain by 19% at the 15% level of inclusion as compared with control. Feed intake did not differ among treatments while feed conversion declined in a linear manner (p=0.04) as the level of linseed meal in the diet increased. Linseed meal inclusion rates of 10% or greater produced a noticeable decline in feed conversion during the finishing period with the 10 and 15% inclusion level of linseed meal producing declines of 5.8% and 20.0% in feed conversion.

Over the entire experimental period (20-95 kg), daily gain declined in a linear manner (p=0.02) with gain being reduced 18.9% for the 15% linseed meal diet compared with the control. Feed conversion also declined (p=0.05) with a 16.9% reduction for the 15% linseed meal diet.

There has been very little research conducted to determine the nutritive value of linseed meal for pigs. Bethke et al. (1928) conducted one of the earlier comparative studies with linseed meal and compared it to cottonseed meal. They fed diets containing 25% linseed meal to pigs with no apparent adverse effects but it should be noted that cottonseed is of much poorer quality as a protein source for use in swine diets compared with soybean meal (Tanksley, 1990). Wahlstrom et al. (1956) found that linseed meal was protective against selenium toxicity but no comparative growth studies were conducted by these authors.

Since the diets used in the present experiment were formulated to supply equal levels of digestible lysine and the sulfur amino acids which are the most limiting in linseed meal protein (Bowland, 1990), it is unlikely that an amino acid deficiency can account for the failure of linseed meal to support pig growth at a similar level as was obtained with soybean meal. However, linseed meal does contain some anti-nutritional factors (Bowland, 1990) and it is possible that one or more of these may account for the poor performance of pigs fed high levels of linseed meal.

Linseed, particularly immature linseed, may contain a cyanogenic glucoside called linamarin which, when acted upon by an associated enzyme, linase, in the seeds, yields hydrocyanic acid (Boucque and Fiems, 1988). The enzyme, linase, is normally destroyed by the heat to which ground linseed is subjected to in oil

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

	Level of linseed meal (%)					Polynomial contrast[1]		
	0	5	10	15	SEM[2]	L	Q	C
Growing period (20.2 to 49.2 kg)								
Daily gain (kg)	0.73	0.70	0.71	0.61	0.02	0.03	NS	NS
Daily feed (kg)	1.68	1.64	1.68	1.49	0.09	0.09	NS	NS
Feed conversion	2.29	2.34	2.38	2.44	0.02	0.05	NS	NS
Finishing period (49.2 to 95.1 kg)								
Daily gain (kg)	0.83	0.79	0.77	0.67	0.02	0.05	NS	NS
Daily feed (kg)	2.68	2.54	2.62	2.57	0.02	NS	NS	NS
Feed conversion	3.20	3.22	3.40	3.84	0.03	0.04	NS	NS
Entire experiod (20.2 to 95.1 kg)								
Daily gain (kg)	0.79	0.75	0.73	0.64	0.03	0.02	NS	NS
Daily feed (kg)	2.23	2.14	2.20	2.12	0.10	NS	NS	NS
Feed conversion	2.83	2.84	3.02	3.31	0.03	0.03	NS	NS

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

extraction. However, when the oil is removed under low-temperature processing conditions, a part of the linamarin and linase remains unchanged in the meal and such meal has caused the death of some animals (Peterson, 1958).

One of vitamin B_6 antagonists called linatine has been isolated and synthesized from linseed meal (Klostermann et al., 1967). Bishara and Walker (1977) reported that pigs fed diets containing 30% linseed meal showed higher gain if supplemental pyridoxine was added to the diet. It has been suggested that, under some conditions, diets containing linseed meal may be marginally deficient in vitamin B_6 which may account for the poorer performance of pigs fed high amounts of linseed meal (Bishara and Wallker, 1977).

IMPLICATIONS

There was a good agreement between the amino acid digestibilities for lysine, methionine, threonine and tryptophan determined using the regression technique and those previously published for linseed meal. These values were then applied in a growth trial to determine the performance of growing-finishing pigs fed graded levels of linseed meal in diets formulated on an ileal digestible amino acid basis. The overall results suggest that linseed meal can be used at levels of between 5 and 10% in diets fed to growing-finishing pigs provided that the diet has been balanced for digestible amino acids.

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