Optimal Threonine:Lysine Ratio for Growing Pigs of Different Sexes**

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ABSTRACT : This study was conducted to investigate the effects of threonine:lysine ratios on growth performance, apparent nutrient digestibility and blood urea nitrogen (BUN) concentration, and to estimate the optimal threonine:lysine ratios for growing barrows and gilts. A total of 150 pigs (Landrace×Yorkshire×Duroc, 16.75±0.42 kg average body weight, 75 barrows and 75 gilts) was randomly allotted into six treatments in a 2×3 factorial design. Six diets were formulated to contain 1.12% lysine for barrows and 1.33% lysine for gilts with three threonine:lysine ratios (50, 60 and 70%) for both barrows and gilts. Throughout the whole experimental period (16 to 56 kg body weight), there was no interaction between sex and dietary threonine:lysine ratio in average daily gain (ADG), average daily feed intake (ADFI) and feed conversion rate (FCR). Between sexes, there was a clear sex-effect showing better growth performance of barrows. Barrows consumed more feed ($p<0.01$) and grew faster ($p<0.01$) than gilts. For barrows, there was a trend to improved ADG and FCR with increasing threonine:lysine ratio. For gilts, there was a trend to improved ADG and FCR up to threonine:lysine ratio of 60%, but not significant. There was no interaction between sex and threonine:lysine ratio in nutrient digestibilities of growing pigs except for crude ash (CA). Between sexes, there were differences in nutrient digestibilities, except for calcium for which gilts showed higher a digestibility ($p<0.01$). Among dietary threonine:lysine ratios, there were no differences in nutrient digestibilities. Mean values of essential amino acids (EAA), non-essential amino acids (NEAA) and total amino acids (TAA) digestibilities were not affected by sex and dietary threonine:lysine ratio. There was no evidence of an interaction between sexes and dietary threonine:lysine ratio. Between sexes, total BUN concentration was lower in gilts than barrows ($p<0.05$). It was concluded that a 70 and 60% dietary threonine:lysine ratio for barrows (1.12% lysine) and gilts (1.33% lysine) tended to result in better growth performances and nutrient utilization and lower BUN concentration than other threonine:lysine ratios. *(Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 12 : 1731-1737)*

Key Words : Sexes, BUN, Growing Pig, Growth Performance, Amino Acid Digestibility, Threonine:Lysine Ratio

INTRODUCTION

Threonine is an important nutrient in swine diets. It is the third limiting amino acid in corn (Grosbach et al., 1985) and may be the second limiting amino acid in grain sorghum (Eckert and Allee, 1974; Cohen and Tanksley, 1976), barley (Fuller et al., 1979a), wheat (Allee and Hines, 1971) and other feedstuffs. Furthermore, when crystaline lysine is incorporated into low protein diets based on wheat (Fuller, 1979a, b) or grain sorghum (Hansen, 1993; Hansen et al., 1993), threonine may become the first-limiting amino acid. Hansen et al. (1993) showed that a 14% CP, lysine-threonine fortified, sorghum-soybean meal diet could produce performance equal to that on 16% CP diet.

Threonine requirements for growing pigs estimated by different researchers show wide variation. Chung and Beames (1974) reported that the optimal L-threonine level was 0.29% for growing pigs fed barley-based diets. However, using corn-based diets, Grosbach et al. (1985) indicated that 0.54% L-threonine was needed for optimal growth performance of pigs. Russel et al. (1986) found that 0.60% L-threonine in corn-soybean meal based diet optimized weight gain and feed efficiency. The current estimation of threonine requirement suggested by NRC has been increased from 0.48% (1988) to 0.61% (1998). The obvious differences in reported threonine requirement may have resulted from variation of reference sources such as weight range and genotype of pigs, diet type and dietary amino acid profile. Of those, amino acid profile plays an important role in estimation of threonine requirement.

Cole (1978) reported that the optimal threonine: lysine ratio was 60% to maximize growth performance in pigs of 25 to 100 kg body weight. Moughan and Smith (1984) reached the similar conclusion that faster growth rate was attained when a threonine:lysine ratio of 59% was incorporated into the diet of pigs in the range of 20 to 80 kg body weight. Wang and Fuller demonstrated that the optimal threonine:lysine ratio was 72% (1989). The optimal ratio suggested by ARC (1981) was 60%, while that by NRC (1998) was 65% for growing pigs. However, until now, there have been

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few available data on whether the optimal threonine: lysine ratio differed according to the sex of growing pigs.

Thus, this study was conducted to estimate the optimal threonine:lysine ratio for growing barrows and gilts by evaluating the effects of ratio on growth performance, nutrient digestibility, amino acid digestibility and BUN concentration.

MATERIALS AND METHODS

Three way crossbred (Yorkshire×Landrace×Duroc) pigs averaging 16.75±0.43 kg BW were used in the trial. Seventy-five barrows and seventy-five gilts were randomly allotted into 6 different treatments with 5 replications in each treatment by a 2×3 factorial arrangement.

Diets were formulated to meet or exceed the nutrient requirements for growing pigs suggested by NRC (1998). They contained two lysine levels, 1.12% for barrows and 1.33% for gilts and three threonine: lysine ratios of 50%, 60% and 70% for both barrows and gilts (table 1).

Barrows and gilts were penned separately in a environmentally controlled growing unit. Pigs were allowed *ad libitum* access to diets from self-feeders and to water from nipple waterers. Pigs were weighed and feed intake was recorded at days 14, 28 and 49 during the whole experimental period.

Blood samples were collected from five pigs per treatment on days 14, 28 and 49 of the experiment. Pigs were bled via puncture from the jugular vein 4 h after feeding. Blood samples were collected into heparinized tubes (Nipro PS-0707, Nissho Co., Japan). After blood sample collection, all samples were quickly transferred to centrifuge tubes and then centrifuged for 15 min at 3,000 rpm in a cold chamber (5℃). The plasma was carefully removed to plastic vials and stored at -20℃ for blood urea analysis. Total blood urea nitrogen concentration was analyzed by blood analyzer (Ciba-Corning model, Express Plus, Ciba Corning Diagnostics Co.).

Table 1. Formula and chemical composition of diets

	Barrows			Gilts		
Threonine:lysine (%)	50	60	70	50	60	70
(Lysine, %)	(1.12)	(1.12)	(1.12)	(1.33)	(1.33)	(1.33)
Ingredients (%)						
Yellow corn (CP 8.3%)	65.65	56.99	57.07	56.65	62.40	65.65
Yellow corn (CP 24.8%)	14.00	14.00	14.00	14.00	14.00	14.00
Soybean meal	14.50	17.59	17.26	16.69	16.35	14.50
Animal fat	1.69	4.16	4.27	4.60	4.75	1.69
Dried molassess	4.00	4.00	4.00	4.00	4.00	4.00
Limestone	0.67	0.50	0.47	0.66	0.63	0.67
Tri-calcium phosphate	1.28	1.28	1.30	1.30	1.32	1.28
Lysine	0.83	0.47	0.49	0.77	0.79	0.83
Methionine+Cystine	0.21	0.14	0.15	0.22	0.22	0.21
Threonine	0.42	0.12	0.24	0.13	0.37	0.42
Salts	0.30	0.30	0.30	0.30	0.30	0.30
Trace mineral premix[1]	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin mixture[2]	0.25	0.25	0.25	0.25	0.25	0.25
Total	100.00	100.00	100.00	100.00	100.00	100.00
Calculated nutrient value[3]						
DE (Mcal/kg)	3.50	3.50	3.50	3.50	3.50	3.50
Crude protein (%)	17.00	17.00	17.00	17.00	17.00	17.00
Lysine (%)	1.12	1.12	1.12	1.33	1.33	1.33
Methionine+cystine (%)	0.67	0.67	0.67	0.73	0.73	0.73
Threonine (%)	0.56	0.67	0.78	0.67	0.80	0.93
Tryptophan (%)	0.17	0.17	0.17	0.17	0.16	0.16
Calcium (%)	0.80	0.80	0.80	0.80	0.80	0.80
Phosphate (%)	0.65	0.65	0.65	0.65	0.65	0.65

[1] Provided the following per kilogram of diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu, 54.1 mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[2] Provided the following per kilogram of diet: vitamin A, 8,000 IU; vitamin D_3, 1,600 IU; vitamin E, 32 IU; d-biotin, 64 μg; riboflavin, 3.2 mg; calcium pantothenic acid, 8 mg; niacin, 16 mg; vitamin B_{12}, 2 μg; vitamin K, 2.4 mg.

[3] Calculated values.

Table 2. Effects of threonine:lysine ratios on growth performance in growing pigs

Threonine:lysine ratio	Barrows			Gilts			Mean	SE[1]
	50	60	70	50	60	70		
ADG (g/day)	830.88[ab]	854.00[a]	874.16[a]	778.75[b]	790.07[b]	773.06[b]	816.82	11.93
ADFI (kg/day)	1.85	1.87	1.83	1.67	1.68	1.69	1.75	0.04
F/G	2.22	2.18	2.08	2.15	2.13	2.19	2.16	0.03

Interactions	ADG	ADFI	F/G
Sex	0.0002	0.0070	NS[2]
Threonine:lysine ratio	NS	NS	NS
Sex × ratio	NS	NS	NS

[1] Pooled standard error.
[2] NS = Not significant.
[a,b] Values with different superscripts within the same row are significantly different ($p<0.05$).

Fifteen barrows and fifteen gilts (averaging 16± 0.14 kg body weight) were penned in individual metabolic cages to determine apparent nutrient digestibilities of pigs. Cr_2O_3 was added into the diets at a rate of 0.25% as an indigestible marker. After four days of adaptation period in the cage (before they moved into metabolic cage, they were adapted to experimental diets for 10 days), pigs were subjected to a 3 d collection period. Collected excreta were pooled, sealed in plastic bags, and stored at -20℃ until they were dried in an air-forced drying oven at 60℃ for 72 hours. Dried fecal samples were ground with 1 mm Wiley Mill for chemical analyses.

Proximate analysis of experimental diets and fecal samples was carried out according to AOAC (1990) methods. Chromium was assayed by Atomic Absorption Spectrophotometer (Shimadzu, AA625, Japan). Amino acids in the experimental feed and in feces samples were determined, following acid hydrolysis with 6 N HCl at 110℃ for 24 hours, using an amino acid analyzer (Biochrom 20, Pharmacia Biotech, England). Sulfur-containing amino acids were analyzed after cold performic acid oxidation (Moore, 1963) overnight, and subsequent hydrolysis. Gross energy value of dietary and fecal samples were measured using an Adiabatic Oxygen Bomb Calorimeter (Model 1241, Parr Instrument Co., Molin, IL). Statistical analysis was carried out by comparing means using Duncan's multiple range (Duncan, 1955) test, by General Linear Model (GLM) Procedure of SAS (1985) package program.

RESULTS AND DISCUSSION

Growth performance

Effects of dietary threonine:lysine ratios on the growth performance in growing barrows and gilts are presented in table 2. Throughout the whole experimental period (16 to 56 kg body weight), there was no interaction between sexes and dietary threonine:lysine ratios on average daily gain (ADG), average daily feed intake (ADFI) and feed conversion rate (FCR). Between sexes, there was a clear sex-effect showing a better growth performance of barrows. Barrows consumed more feed ($p<0.01$) and grew faster ($p<0.01$) than gilts. For barrows, there was a trend to improved ADG and FCR with increasing threonine:lysine ratio. For gilts, there was a trend to improved ADG and FCR up to a threonine:lysine ratio of 60%. Average daily feed intake was not affected by increasing dietary threonine:lysine ratios. Total lysine intake was not affected by sex and dietary threonine:lysine ratio.

In previous studies, NRC (1998) recommended a dietary threonine:lysine ratio of 65% for growing pigs (20 to 50 kg body weight) for maximum growth performance. Similarly, Williams et al. (1993) reported that threonine:lysine ratios of 64% and 68% for grower and finisher pigs, respectively, produced optimal growth performance and protein retention. Current estimations of requirements suggest that the ratio of threonine:lysine should be increased along with animal weight and the associated increase of maintenance requirements (Baker and Chung, 1992). Tillis (1981) reported that maximum protein accretion and body weight were obtained at 73 and 78% threonine:lysine ratios for 20 and 50 kg gilts, respectively.

Even though the result of present experiment did not show a clear response in growth performance with increasing dietary threonine:lysine ratio, ratios of 70 and 60% for barrow and gilts respectively showed better ADG and FCR compared to other dietary ratios.

In the present study, there existed an evident relationship between growth performance and sex. The evident advantage in weight gain and feed efficiency was found in barrows compared with gilts. This partially agreed with the results from a previous study by Cromwell et al. (1993), who reported that barrows grew faster than gilts ($p<0.01$), but gilts required less

Table 3. Effects of threonine:lysine ratios on apparent digestibilities of nutrients and energy in growing pigs

Threonine:lysine ratio	Barrows			Gilts			Mean	SE[1]
	50	60	70	50	60	70		
GE	67.84	72.75	74.25	67.22	72.77	72.83	71.27	1.24
DM	70.27	74.38	75.70	67.48	74.02	73.30	72.52	1.22
CP	62.11	64.62	65.00	53.85	64.69	61.85	62.02	1.51
CF	16.73	29.26	35.31	25.03	36.91	32.23	29.24	2.58
CA	32.48[ab]	23.82[b]	39.59[ab]	22.45[b]	44.31[a]	35.46[ab]	33.02	2.55
Ca	49.08[c]	57.08[bc]	71.66[a]	66.31[ab]	67.97[a]	68.48[a]	63.43	2.05
P	36.96	20.63	32.33	21.49	32.49	28.37	28.71	2.31

Interactions	GE	DM	CP	CF	CA	Ca	P
Sex	NS[2]	NS	NS	NS	NS	0.0036	NS
Threonine:lysine ratio	NS	NS	NS	NS	NS	NS	NS
Sex × ratio	NS	NS	NS	NS	0.0400	NS	NS

[1] Pooled standard error.

[2] NS = Not significant.

[a,b,c] Values with different superscripts within the same row are significantly different ($p<0.05$).

Abbreviations: GE, gross energy; DM, dry matter; CP, crude protein; CF, crude fat; CA, crude ash; Ca, calcium.

feed per unit of gain ($p<0.05$) and had a greater percentage of carcass muscle ($p<0.01$) than did barrows. Similarly, Friesen et al. (1994) showed that barrows achieved greater ($p<0.05$) ADG and ADFI but exhibited a poorer ($p<0.01$) G/F than gilts, whereas gilts increased ($p<0.01$) CP accretion and decreased ($p<0.01$) lipid accretion compared with barrows.

Threonine requirement for maintenance in pigs tends to increase with increasing body weight and age (Black and Davies, 1991; Williams et al., 1993). In this study a similar tendency was observed in both barrows and gilts, but barrows tended to require a higher threonine:lysine ratio probably due to the difference in lysine requirement.

Apparent digestibilities of proximate nutrients and amino acids

The effects of three different threonine:lysine ratios on nutrient digestibilities in growing barrows and gilts are shown in table 3. There were no interactions between sexes and threonine:lysine ratio in digestibilities except for crude ash (CA). Between sexes, no differences in nutrient digestibilities were observed except for Ca for which gilts showed a higher digestibility ($p<0.01$). Among dietary threonine: lysine ratios, there were no significant differences in digestibilities.

In the present experiment, the responses in apparent digestibilities of nutrients basically coincided with responses in growth performances. Generally, digestibilities of nutrients were higher in barrows and gilts fed on diet with 70 and 60% dietary threonine: lysine ratios respectively. Table 4 summarizes the effects of threonine:lysine ratios on amino acid digestibilities. Mean values for the essential amino acids (EAA), non-essential amino acids (NEAA) and total amino acids (TAA) digestibilities were not affected by sex. However, digestibility of threonine was higher in gilts than barrows ($p<0.05$). Among dietary threoine:lysine ratios, no differences in mean values for EAA, NEAA and TAA digestibilities were observed. For barrows, the 70% threonine:lysine ratio group showed higher digestibilities of NEA and TAA than the other ratio groups. For gilts, the 60% threonine:lysine ratio group showed higher digestibilities of EAA, NEAA and TAA than the other groups. In the present study, different threonine:lysine ratios in diets did not significantly affect crude protein and total amino acid digestibilities in barrows and gilts.

Blood urea nitrogen

Table 5 shows the effects of threonine:lysine ratio on blood urea nitrogen (BUN) concentration. There was no evidence of an interaction between sex and dietary threonine:lysine ratio. Between sexes, total BUN concentration was lower in gilts than barrows ($p<0.05$). However, BUN concentration was not affected by increasing dietary threonine:lysine ratios.

Measuring BUN concentrations can offer an alternative and simpler means of assessing requirements for dietary protein (Chen et al., 1995). Changes in BUN concentration in response to altered dietary levels of amino acids have been utilized previously to estimate amino acid requirements of growing-finishing pigs (Lewis et al., 1980; Yen et al., 1986a, b; Coma and Zimmerman, 1993). This is because animals have little ability to store amino acids in a free state. Therefore, if amino acids are not immediately required for protein synthesis they are readily broken down and either deaminated or used as an energy source. Amino acids pools exceeding the requirement are therefore catabolized, then causing a sharp rise in BUN

Table 4. Effects of threonine:lysine ratios on apparent digestibilities of amino acids in growing pigs

Threonine:lysine ratio	Barrows 50	Barrows 60	Barrows 70	Gilts 50	Gilts 60	Gilts 70	Mean	SE[1]
Threonine	54.37[a]	50.94[b]	57.55[a]	56.66[a]	60.52[a]	63.14[a]	53.86	3.07
Valine	69.60	69.52	77.62	64.67	58.00	56.88	66.05	2.80
Methionine	64.87[ab]	53.51[b]	62.45[ab]	62.98[ab]	76.96[a]	48.78[b]	61.59	2.70
Cystein	58.42[b]	81.41[a]	71.26[ab]	79.30[ab]	61.68[ab]	65.41[ab]	69.58	2.92
Isoleucine	66.39[ab]	57.82[ab]	76.36[a]	67.87[ab]	66.73[ab]	48.34[b]	63.92	2.78
Leucine	66.97	78.18	72.25	68.68	68.01	78.34	72.07	1.65
Phenylalanine	70.39	69.27	76.70	65.16	60.69	60.46	67.11	2.68
Histidine	70.67	75.22	74.59	65.79	71.09	62.91	70.04	2.12
Lysine	76.61	69.52	74.69	69.52	64.91	63.57	69.80	1.75
Arginine	62.41[c]	75.81[bc]	75.78[bc]	62.80[c]	91.53[a]	79.95[ab]	74.71	2.55
EAA	66.07	66.12	71.93	66.34	66.12	62.78	66.87	1.52
Aspartate	61.94	61.83	66.13	75.13	69.15	77.64	68.64	2.09
Serine	62.66[ab]	64.31[ab]	62.29[ab]	49.77[b]	73.42[a]	50.54[b]	60.49	2.38
Glutamate	72.21	80.16	82.18	84.23	86.83	79.66	80.88	1.98
Proline	67.41[b]	72.99[ab]	61.29[b]	70.08[ab]	73.08[a]	94.97[a]	73.30	3.49
Glycine	60.90	64.59	57.22	52.86	63.63	61.41	60.10	1.88
Alanine	71.98[a]	52.26[b]	59.72[ab]	58.76[ab]	56.33[ab]	55.84[ab]	59.15	2.22
Tyrosine	76.12[a]	77.64[a]	70.22[ab]	55.64[c]	56.57[bc]	43.53[c]	63.29	3.02
NEAA	67.60	67.68	65.58	63.78	68.43	66.23	66.55	1.39
TAA	66.84	66.90	68.75	65.06	68.22	64.50	66.71	1.32

Interaction	THR	VAL	MET	CYS	ILE	LEU	PHE	HIS	LYS	ARG
Sex	0.0247	0.0285	NS[2]	NS	NS	NS	NS	NS	0.0386	NS
Threonine:lysine ratio	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0007
Sex × ratio	NS	NS	0.0128	0.0201	0.0177	NS	NS	NS	NS	NS

Interaction	EAA	ASP	SER	GLU	PRO	GLY	ALA	TYR	NEA	TAA
Sex	NS	0.0206	NS	NS	NS	NS	NS	0.0001	NS	NS
Threonine:lysine ratio	NS	NS	0.0334	NS	NS	NS	NS	NS	NS	NS
Sex × ratio	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1] Pooled standard error. [2] NS = Not significant.

[a,b,c] Values with different superscripts within the same row are significantly different ($p<0.05$).

Abbreviations: EAA, essential mino acids; NEAA, non-essential amino acids; TAA, total amino acids; THR, threonine; VAL, valine; MET, methionine; ILE, isoleucine; LEU, leucine; PHE, phenylalanine; HIS, histidine; LYS, lysine; ARG, arginine; ASP, aspartic acid; SER, serine; GLU, glutamine; PRO, proline; GLY, glycine ALA, alanine; TYR, tyrosine.

Table 5. Effects of threonine:lysine ratios on blood urea nitrogen in growing barrows and gilts (mg/dL)

Threonine:lysine ratio	Barrows 50	Barrows 60	Barrows 70	Gilts 50	Gilts 60	Gilts 70	Mean	SE[1]
14 th day	6.56[a]	5.73[ab]	4.52[ab]	3.83[b]	4.42[b]	4.75[ab]	4.97	0.29
28 th day	8.22[a]	6.66[ab]	6.46[ab]	4.95[b]	4.83[b]	6.83[ab]	6.33	0.37
49 th day	9.59	8.90	9.00	7.75	6.44	8.53	8.37	0.50
Mean	8.08	7.32	6.76	5.79	5.43	6.64	6.67	0.34

Interactions	D 14	D 28	D 49	Total
Sex	0.0268	0.0267	NS[2]	0.0461
Threonine:lysine ratio	NS	NS	NS	NS
Sex × ratio	NS	NS	NS	NS

[1] Pooled standard error. [2] NS = Not significant.

[a,b] Values with different superscripts within the same row are significantly different ($p<0.05$).

concentration.

In this experiment, the lower BUN concentrations in gilts than barrows were partially associated with sex differences in rate of protein deposition. It has been

demonstrated that barrows utilized feed less efficiently and have fatter carcasses than gilts (Cromwell et al., 1993). This difference in BUN concentration between sexes was similar to the results observed by Cai et al. (1996) and Yen et al. (1986a, b).

In the present experiment, there was a tendency that 70 and 60% dietary threonine:lysine ratio groups for barrows and gilts, respectively, showed lower BUN concentrations than the other threonine:lysine ratio groups.

Based on results from four criteria (growth performance, proximate nutrients digestibility, amino acid digestibility, and BUN concentrations), it is likely that the optimal ratios of threonine:lysine for maximum growth performance and nutrient utilization could be 70 and 60% for barrows and gilts at the lysine level of 1.12% for barrows and 1.33% for gilts, respectively.

REFERENCES

Allee, G. L. and R. H. Hines. 1971. Amino acid supplementation of wheat and milo for the finishing pig. Rep. Progr. No. 181. Swine Industry Day. Kansas State Univ. p. 1.

AOAC. 1990. Official Methods of Analysis (15th ED.). Association of Official Analytical Chemists, Arlington. VA., USA.

ARC. 1981. The Nutrient Requirement of pigs. Commonwealth Agricultural Bureaux. Slough, UK.

Baker, D. H. and T. K. Chung. 1992. Ideal protein for swine and Poultry Biokyowa Technical Review 4, Chesterfield: Nutr., Quest, Inc.

Black, J. L. and G. T. Davies. 1991. Ideal protein: Its variable composition. In: Manipulating Pig Production Ⅲ (Ed. E. S. Batterham). Australasian Pig Science Association Attwood, Victoria, Australia. p. 111.

Cai, Y., R. C. Ewan and D. R. Zimmerman. 1996. Effects of dietary protein and potassium contents on plasma urea nitrogen and amino acids in relation to performance of swin. Can. J. Anim. Sci. 76:351.

Chen, H. Y., P. S. Miller, A. J. Lewis. C. K. Wolverton and W. W. Stroup. 1995. Changes in plasma urea concentration can be used to determine protein requirements of two populations of pigs with different protein accretion rates. J. Anim. Sci. 73:2631.

Chung, A. S. and R. M. Beames. 1974. Lysine, threonine, methionine and isoleucine supplementation of Peace River barley for growing pigs. Can. J. Anim. Sci. 54:429.

Cohen, R. S. and T. D. Tanksley, Jr. 1976. Limiting amino acids in sorghum for growing and finishing pigs. J. Anim. Sci. 43:1208.

Cole, D. J. A. 1978. Amino acid nutrition of the pig. In: Recent Advances in Animal Nutrition (Ed. W. Haresign and D. Lewis). Butterworths. London.

Coma, J. and D. R. Zimmerman. 1993. Lysine requirement of finishing pigs determined by using plasma urea nitrogen in short time trials. J. Anim. Sci. 71(Suppl. 1.):168(Abstr.).

Cromwell, G. L., T. R. Cline, J. D. Crenshaw, T. D. Crenshaw, R. C. Hamilton, C. R. Hamilton, A. J. Lewis, D. J. Mahan, E. R. Miller, J. E. Pettigrew, L. F. Tribble and T. L. Veum. 1993. The dietary protein and lysine requirements of barrows and gilts. J. Anim. Sci. 71:1510.

Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics. 11:1.

Eckert, T. E. and G. L. Allee. 1974. Limiting amino acids in milo for the growing pigs. J. Anim. Sci. 39:694.

Friesen, K. G., J. L. Nelson, J. A. Unruh, R. D. Goodband and M. D. Tokach. 1994. Effects of the interrelationship between genotype, sex and dietary lysine on growth performance and carcass composition in finishing pigs fed to either 104 or 127 kilograms. J. Anim. Sci. 72:946.

Fuller, M. F., I. Mennie and R. M. J. Crofts. 1979b. The amino acid supplementation of barley for the growing pig. 2. Optimal additions of lysine and threonine for growth. Br. J. Nutr. 41:333.

Fuller, M. F., R. M. Livingstone, B. A. Baird and T. Atkinson. 1979a. The optimal amino acid supplementation of barley for the growing pig. 1. Responses of nitrogen metabolism to progressive supplementation. Br. J. Nutr. 41:321.

Grosbach, D. A., A. J. Lewis and E. R. Peo, Jr. 1985. An evaluation of threonine and isoleucine as the third and fourth limiting amino acids in corn for growing swine. J. Anim. Sci. 60:487.

Hansen, J. A. 1993. Amino acid supplementation of low-protein sorghum-soybean meal diets for 5 to 20-kilogram swine. J. Anim. Sci. 71:452.

Hansen, J. A., D. A. Knable and K. G. Burgoon. 1993. Amino acid supplementation of low protein sorghum-soybean meal diets for 20 to 50 kilogram swine. J. Anim. Sci. 71:442.

Lewis, A. J., E. R. Peo, Jr, B. D. Moser and T. D. Crenshaw. 1980. Lysine requirement of pigs weighing 5 to 15 kg fed practical diets with and without added fat. J. Anim. Sci. 51:361.

Moore, S. 1963. On the determination of cystine as cysteric acid. J. Biol. Sci. 238:235-237.

Moughan, P. J. and W. C. Smith. 1984. Assessment of a balance of dietary amino acids required to maximize protein utilization in the growing pig (20~80 kg live weight). N. Z. J. Agric. Res. 30:301.

NRC. 1988. Nutrient Requirements of Swine (9th Ed.). National Academy Press, Washington, DC.

NRC. 1998. Nutrient Requirements of Swine (10th Ed.). National Academy Press, Washington, DC.

Russell, L. E., R. A. Easter, V. Gomez-Rojas, G. L. Cromwell and T. S. Stahly. 1986. A note on the supplementation of low-protein, maize-soya-bean meal diets with lysine, tryptophan, threonine and methionine for growing pigs. Anim. Prod. 42:291.

SAS. 1985. SAS User's Guide: Statics, SAS Inst. Inc., Cary. NC.

Tillis, J. B. 1981. Protein Growth in Pigs. Ph. D. Thesis. Univ. of Edinburgh.

Wang, T. C. and M. F. Fuller. 1989. The optimal dietary amino acid pattern for growing pigs. 1. Experiments by amino acid deletion. Br. J. Nutr. 62:77.

Williams, K. C., P. R. Martin and M. H. Magee. 1993. The optimal dietary threonine to lysine ratio for growing pigs.

In: Recent Advances in Animal Nutrition in Australia. University of New England, Armidale, Australia. p. 213.

Yen, H. T., D. J. A. Cole and D. Lewis. 1986a. Amino acid requirements of growing pigs. 7. The response of pigs from 25 to 55 kg live weight to dietary ideal protein. Anim. Prod. 43:141.

Yen, H. T., D. J. A. Cole and D. Lewis. 1986b. Amino acid requirements of growing pigs. 8. The response of pigs from 50 to 90 kg live weight to dietary ideal protein. Anim. Prod. 43:155.