The Effect of Lysine to Protein Ratio on Growth Performance and Efficiency of Nitrogen Utilization in Pigs**

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ABSTRACT : One feeding trial and two metabolic trials were conducted to investigate the effects of lysine to protein ratio in practical swine diets on growth performance and efficiency of nitrogen retention and utilization in different growing phases. In Trial one (the feeding trial), 90 mixed sex pigs weighing 9.1±1.4 kg (Duroc × Landrance × Beijing Black) were used to study the effects of concentrations of 5.2, 5.3, 5.8, 6.4 and 7.2 g lysine/100 g CP in diets containing 1.2% lysine on growth performance and serum urea nitrogen. The results showed that feed conversion efficiency and economic efficiency were best for pigs fed the diet containing the lysine concentration of 5.8 g /100 g crude protein. Serum urea nitrogen concentration decreased linearly (p=0.0009) and serum free lysine content increased linearly (p=0.0017) as the lysine to protein ratio in diets increased from 5.2 to 7.2 g/100 g. In Trials two and three (the metabolic trials), five growing barrows (Duroc × Landrance × Beijing black), with initial body weights of approximately 26±2.4 kg and 56.3±3.5 kg, respectively, were allotted to five dietary treatments according to a 5 × 5 Latin square design. Trial two contained 5.2, 5.7, 6.1, 6.7 and 6.8 g lysine/100 g CP treatments. Trial three contained 4.6, 5.0, 5.6, 6.1 and 6.6 g lysine/100 g CP treatments. The results showed that nitrogen retention in growing pigs decreased linearly (p=0.0011 in Trial two; p=0.0099 in Trial three) as the lysine to protein ratio in diets increased. The ratio of lysine to protein in diets resulting in maximum nitrogen retention was 5.2 g/100 g and 5.0 g/100 g in Trial two and Trial three, respectively. In Trial two, apparent biological value and gross nitrogen efficiency increased linearly (p=0.0135 and p=0.0192, respectively) as the lysine to protein ratio increased from 5.2 to 6.8 g lysine/100 g CP. In summary, we concluded that the optimal Lysine to Protein Ratios for 8-20 kg and 20-80 kg pigs were 5.8 g/100 g and 5.0 to 5.2 g/100 g, respectively. *(Asian-Aust. J. Anim. Sci. 2001. Vol 14, No. 9 : 1282-1289)*

Key Words : Lysine to Protein Ratio, Pig, Growth Performance, Nitrogen Retention, Nitrogen Digestibility

INTRODUCTION

Most ideal protein studies have assessed the appropriate ratio of lysine to other indispensable amino acids, but have not determined the optimal ratio of indispensable to dispensable amino acids. The ratio of indispensable to dispensable amino acids at a given dietary protein level is also important and is determined by the ratio of lysine to protein. Wang and Fuller (1989) estimated the optimal ratio of lysine to protein for weanling pigs in a diet supplemented with synthetic amino acids in the range of 6.5 to 7.0 g/100 g. The lysine to protein ratio for 10-20 kg pigs recommended by NRC (1998) is 5.5 g/100 g. The China Lean Swine Feed Standard (1987) recommends a ratio of lysine to protein for 10-20 kg pigs of about 4.1 g/100 g, which is lower than the values recommended by Wang and Fuller (1989) and NRC (1998). However, the three-phase feeding system for piglets (0-5 kg, 5-10 kg and 10-20 kg) recommended by NRC (1998) is not suitable for practical conditions in China, where the optimal age for weaning piglets is five weeks and the feeding system is divided into only two phases (0-8 kg and 8-20 kg). Some researchers have studied the optimal ratio of lysine to protein for 8-20 kg pigs, but the results varied greatly. Further research is needed to determine the optimal ratio of lysine to protein for five-week-old weaned pigs.

NRC (1998) recommends a ratio of lysine to protein for 20-50 kg and 50-80 kg growing pigs of 5.7 and 4.5 g lysine/100 g CP, respectively. The ratios of lysine to protein recommended by the China Lean Swine Feed Standard (1987) are 4.7 and 4.5 g lysine/100 g CP for 20-60 kg and 60-90 kg pigs, respectively, which are, again, lower than those recommended by NRC (1998). Recently, swine breeds in China have been greatly improved, and the growth rate and potential nitrogen retention in growing pigs have increased. Therefore, the ratio of lysine to protein required to support maximum growth rate and maximum nitrogen retention of growing pigs in China needs to be re-investigated. This study was conducted to determine the ratio of lysine to protein in practical diets that is optimum for meeting the growing requirement for 8-20 kg pigs and supporting maximum nitrogen retention in growing pigs.

MATERIALS AND METHODS

Animals and design

In the feeding trial (Trial one), ninety piglets (Duroc × Landrance × Beijing black) weaned at 30±3 days and

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weighing 9.1±1.4 kg, were used. Piglets were allotted to five dietary treatments based on weight and sex (three pens of males and three pens of female per treatment). There were six replicates (or pens) per treatment with three pigs per replication. During the experiment all piglets were housed in an environmentally controlled room. Pen size was 170 cm × 175 cm. Pigs had free access to water from a nipple waterer and feed were fed from metal feeders. Individual piglets were weighed and pen feed consumption was determined at the beginning and at the end of the experiment. On d 14 of the trial, a blood sample was collected from one pig in each pen. Seven ml of blood was collected from the anterior vena cava into a vacuum tube and centrifuged at 3500 rpm for 10 minutes to obtain plasma, which was then stored at -20°C until serum urea nitrogen and serum free amino acids concentrations were measured. The trial period was 21 days.

Two metabolic trials (Trial two and Trial three) were conducted to study the effect of different lysine to protein ratio on efficiency of nitrogen utilization in 20-60 kg and 60-80 kg growing pigs, respectively. In each metabolic trial, five growing barrows (Duroc × Landrance × Beijing black) with initial body weights of approximately 26±2.4 kg and 56.3±3.5 kg, respectively, were allotted to five dietary treatments according to a 5 × 5 Latin square design. All growing pigs were housed in individual steel metabolic cages. The temperature in the pig house was maintained at 20-25°C throughout the trials. All barrows were fed at a rate of 4% (wt/wt) of the average body weight at 08:00 and 17:00 daily and had free access to water. The trials lasted 35 d and were divided into five periods. Each period consisted of a 4-d diet adjustment period and a 3-d total fecal and urine collection period. Pigs were individually weighed at the beginning and at the end of each experimental period. Feed intake per pig was recorded daily. In Trial two, blood samples were collected at the end of the experimental period and centrifuged at 3500 rpm for 10 minutes to obtain plasma. Plasma was stored at -20°C for later measurement of serum urea nitrogen and serum free lysine concentrations.

Diets

All crystalline amino acids used in the three trials were provided by Ajinomoto Animal Nutrition Company (Tokyo, Japan). Each of the three trials contained five diets. Lysine levels in the five diets per trial were relatively constant (Trial one, 1.18%; Trial two 1.10%; Trial three, 0.8%), but CP levels were varied to provide different ratios of lysine to protein (table 1). Other nutrients in the diets met or exceeded NRC (1998) recommendations. The dietary composition and chemical analysis of the diets fed in Trials one, two and three are given in tables 2, 3 and 4, respectively.

Table 1. Total experimental design

Live weight of pigs	Lysine to protein ratio in practical diet (g/100 g)				
8-20 kg	5.2	5.3	5.8	6.4	7.2
20-60 kg	5.2	5.7	6.1	6.7	6.8
60-80 kg	4.6	5.0	5.6	6.1	6.6

Urine and feces collection

On each day of the 3-d collection period, feces and urine were collected every two hours from 8:30 to 17:30 from every pig. Daily feces excretion per pig was recorded and one-fifth of the fresh feces was stored in a -20°C freezer. At the end of d 3 the stored feces of each pig were combined, weighed and homogenized. The samples were then air-dried at 65°C for 48 hours, weighed and ground for analysis of dry matter and nitrogen. The total 24 h urinary output of each pig was recorded and collected into a container containing 10 ml of 10% tartaric acid (v/v) to prevent loss of ammonia and microbial growth. One-tenth of the urine sample was refrigerated at -20°C. At the end of the collection period, all the urine samples from each pig were combined and stored at -20°C until analysis.

Chemical analysis

Samples of all ingredients and diets were analyzed for nitrogen, calcium and total phosphorus content. The nitrogen content of diets, feces and urine was assayed by Kjeldahl method (AOAC 988.05), using a Kejiack auto sampler system 1035 analyzer (Tecator, America). CP is calculated as 6.25×nitrogen content. Dietary calcium and total phosphorus were measured by potassium permanganate titration (AOAC 927.02) and ammonium molybdate chromometry (AOAC 965.05), respectively. Serum urea nitrogen concentration was measured by Auto Biochemical Analyzer (Techicon RA-1000TM, America); serum free lysine concentration was analyzed using an Amino Acid Analyzer (Hitachi L-8800, Japan).

Statistical analysis

Statistical analysis was performed by Spss 6.0 software (SPSS Inc., America). All data from the trials were analyzed using one-way analysis of variance (ANOVA). When ANOVA indicated a significant p value, means were separated using Duncan's multiple range test.

RESULTS

Effects of the lysine to protein ratio in diets on growth performance, serum urea nitrogen and serum free amino acids concentrations

The effects of the lysine to protein ratio on the growth performance of 8-20 kg pigs are shown in table 5. Feed/gain tended to be different (p=0.08), with pigs fed a diet with a

Table 2. Diet compositions and chemical analysis for 8-20 kg piglets (Trial one)

	Lysine to protein ratio (g/100 g)				
	5.2	5.3	5.8	6.4	7.2
Ingredients (% as fed)					
Corn	51.76	56.13	60.65	64.34	67.79
Corn gluten meal	4.00	-	-	-	-
Soybean meal	31.40	30.79	26.00	22.01	18.29
Fishmeal	4.00	4.00	4.00	4.00	4.00
Whey	5.00	5.00	5.00	5.00	5.00
Soybean oil	0.80	1.00	1.00	1.00	1.00
Calcium carbonate	0.60	0.58	0.55	0.54	0.52
Monocalcium phosphate	1.10	1.15	1.25	1.33	1.40
Salt	0.34	0.34	0.34	0.34	0.34
1% Premix[1]	1.00	1.00	1.00	1.00	1.00
Lysine	-	0.01	0.17	0.30	0.42
Methionine	-	-	0.01	0.05	0.09
L-Threonine	-	-	0.03	0.09	0.14
Trptophan	-	-	-	-	0.01
Nutritional level[2](analyzed as fed)					
DE (Mcal/kg)	3.26	3.26	3.26	3.26	3.26
Crude protein (%)	23.51	21.54	20.20	18.56	16.68
Calcium (%)	0.80	0.79	0.81	0.82	0.82
Total phosphorus (%)	0.60	0.60	0.62	0.61	0.61
Lysine (%)	1.21	1.13	1.18	1.18	1.19
Methionine + cystine (%)	0.78	0.70	0.66	0.66	0.66
Threonine (%)	0.89	0.82	0.78	0.78	0.78
Tryptophan (%)	0.32	0.30	0.27	0.25	0.23
Lysine to protein ratio	5.2	5.3	5.8	6.4	7.2

[1] Premix provide per kilogram of complete diet: Vitamins premix, 400 mg ; Choline, 900 mg ; Mn, 127.2 mg ; Fe, 196 mg ; ZnO, 3000 mg; Cu, 50 mg ; I_2, 0.35 mg ; Se, 0.5 mg; Tylosin, 40 mg; Arsanilic acid, 130 mg; Carbadox, 50 mg. [2] All value was analyzed except DE, methionine + cystine, and tryptophan.

lysine to protein ratio of 5.8 exhibiting the best efficiency. Feed/gain in pigs fed the diet with 5.8 g lysine/100 g CP were 13.9%, 6.2%, 4.6% and 10.6% less than that of pigs fed diets with lysine to protein ratios of 5.2, 5.3, 6.4 and 7.2, respectively. ADG and ADFI were not affected by different lysine to protein ratios in the diet. The feed cost per kg weight gain of the 5.8 g lysine/100 g CP diet was 0.83, 0.08, 0.08 and 0.60 ¥ less than the diets having a 5.2, 5.3, 6.4 and 7.2 lysine to protein ratio. The effect of the lysine to protein ratio in the diet on the serum urea nitrogen and serum free amino acid concentration is shown in table 6. Serum urea nitrogen concentration of the 7.2 g/100 g CP diet was significantly lower than those containing 5.2, 5.3 and 5.8 g/100 CP ($p<0.05$); serum urea nitrogen concentration of the 6.4 g/100 g CP diet was significantly lower than those of the 5.2 and 5.3 g/100 g CP diet ($p<0.05$), but not different from those of the 5.8 and 7.2 g/100 CP. When the lysine to protein ratio increased from 5.2 to 7.2, serum urea nitrogen concentration decreased linearly ($p<0.0009$). The serum free lysine concentration of the 7.2 g/100 g CP diet was significantly higher those of the 5.2, 5.3 and 5.8 g/100 g CP diet ($p<0.05$), but serum free lysine concentrations did not differ among the 5.2, 5.3, 5.8 and 6.4 g/100 g CP diet ($p>0.05$; table 6). The serum free lysine concentration increased linearly ($p<0.0017$) and the serum free valine concentration reduced linearly ($p<0.0001$) as the lysine to protein ratio in the diet increased. The concentration of total free amino acids and the concentrations of other than lysine, valine and methionine were not significantly different among the five treatments ($p>0.05$).

Effects of the lysine to protein ratio in diets on nitrogen retention and efficiency of utilization in growing pigs

Table 7 shows how the lysine to protein ratio influenced the efficiency of nitrogen utilization in 20-60 kg growing pigs. Daily nitrogen intake and daily urinary nitrogen excretion decreased linearly ($p=0.0001$ and $p=0.0019$, respectively) with the increase of the lysine to protein ratio in the diet from 5.2 g/100 g to 6.8 g/100 g. Daily nitrogen retention was greatest in pigs fed the diet containing 5.2 g lysine/100 g crude protein; at 25.75 g, it was significantly higher than that of the four other dietary treatments

Table 3. Diet composition and chemical analysis for 20-60 kg growing pigs (Trial two)

	Lysine to protein ratio (g/100 g)				
	5.2	5.7	6.1	6.7	6.8
Ingredients (% as fed)					
Corn	59.03	63.47	68.52	72.45	75.20
Soybean meal	33.35	29.80	24.80	20.70	21.00
Corn gluten meal	4.20	3.00	3.00	3.00	-
Soybean oil	0.22	0.40	0.20	0.20	0.46
Calcium carbonate	1.07	1.07	1.07	1.08	1.11
Monocalcium phosphate	0.65	0.65	0.66	0.70	0.66
Salt	0.30	0.30	0.30	0.30	0.30
1% Premix[1]	1.00	1.00	1.00	1.00	1.00
Lysine	-	0.10	0.23	0.34	0.36
L-Threonine	0.18	0.21	0.22	0.23	0.27
Total	100	100	100	100	100
Nutritional level [2](analyzed as fed)					
DE (Mcal/kg)	3.27	3.27	3.26	3.26	3.26
Crude protein (%)	21.34	19.28	17.32	15.73	14.72
Calcium (%)	0.62	0.61	0.61	0.60	0.60
Total phosphorus (%)	0.52	0.52	0.52	0.53	0.51
Lysine (%)	1.10	1.10	1.05	1.05	1.00
Methionine+cystine (%)	0.70	0.64	0.59	0.55	0.56
Threonine (%)	0.61	0.61	0.61	0.61	0.61
Lysine to protein ratio	5.2	5.7	6.1	6.7	6.8

[1] Provide the following nutrients per kilogram of complete diet; Vitamin A, 5000 IU; Vitamin D_3, 1500 IU; Vitamin E_1, 5 IU; Vitamin K_3, 3 mg; Thiamine, 1 mg; Riboflavin, 3 mg; Pyridoxine, 1.5 mg; Vitamin B_{12}, 10 ug; Niacin, 10 ug; Pantothenic acid, 12 mg; Choline, 320 mg; Fe, 37.8 mg; Cu, 42.5 mg; Zn, 47.25 mg; Mn, 17.49 mg; I, 0.96 mg; Se, 0.72 mg.

[2] All value was analyzed except DE, methionine + cystine, and tryptophan.

($p<0.05$). Daily nitrogen retention decreased linearly ($p=0.0011$) with the increasing ratio of lysine to protein in the diets. The apparent biological value at maximum nitrogen retention was estimated to be 57.4% and the gross efficiency of nitrogen use for maximum nitrogen retention was 51.2%. Apparent biological value and gross nitrogen efficiency increased linearly ($p=0.0135$ and $p=0.0192$) as the ratio of lysine to protein in diets increased from 5.2 g/100 g to 6.8 g/100 g. Apparent digestibility of DM and nitrogen were not significantly different among the diets. Serum urea nitrogen concentration decreased linearly ($p<0.0116$) as the lysine to protein ratio in the diet increased.

Table 8 illustrates how the lysine to protein ratio influenced efficiency of nitrogen utilization in 60-80 kg growing pigs. Daily nitrogen intake was significantly different among the five dietary treatments ($p<0.0000$) and decreased linearly ($p=0.0000$) as the lysine to protein ratio in the diets increased from 4.6 g/100 g to 6.6 g/100 g, respectively. Daily urinary nitrogen excretion also decreased linearly ($p=0.0042$) as the ratio of lysine to protein in the diets increased. Daily nitrogen retention in pigs fed the diet containing 5.0 g lysine/100 g CP was significantly higher ($p<0.05$) than in those fed other diets. The apparent biological value and gross nitrogen efficiency were greatest in pigs fed the 5.0 g lysine/100 g CP diet (51.8% and 47.6%, respectively). Increasing the lysine to protein ratio in diets from 4.6 g/100 g to 6.6 g/100 g had no significant effect on apparent digestibility of DM and nitrogen ($p>0.05$).

DISCUSSION

This study was conducted to determine if different crude protein levels in practical swine diets influenced the growth performance and efficiency of nitrogen utilization in different growing phases. The dietary lysine levels in each trial were relatively constant, but the CP levels in the diets were varied to provide different ratios of lysine to protein.

Trial one studied the effects of CP levels in the diets adding synthetic amino acids on the growth performance, serum urea nitrogen and serum free amino acids concentrations of 8-20 kg pigs. The results showed that when the dietary lysine level was 1.2%, reduction of dietary CP levels from 23.5% to 16.6% did not affect the growth performance of pigs. This result agrees with those reported by Cheng (1997) and Hansen and Lewic (1993). Cheng (1997) studied the effects of CP levels in corn-soybean

Table 4. Diet composition and chemical analysis for 60-80 kg growing pigs (Trial three)

	Lysine to protein ratio (g/100 g)				
	4.6	5.0	5.6	6.1	6.6
Ingredients (% as fed)					
Corn	72.40	75.66	79.40	82.01	84.59
Corn gluten meal	4.93	-	-	-	-
Soybean meal	19.50	21.22	17.27	14.59	11.93
Calcium carbonate	0.83	0.84	0.82	0.81	0.80
Monocalcium phosphate	0.82	0.78	0.86	0.92	0.97
Salt	0.34	0.34	0.34	0.34	0.34
1% Premixe[1]	1.00	1.00	1.00	1.00	1.00
Lysine	0.06	0.04	0.02	0.03	0.04
Methionine	0.12	0.12	0.25	0.29	0.32
L-Threonine	-	-	0.04	0.01	0.01
Total	100	100	100	100	100
Nutrient level [2] (analyzed as fed)					
DE (Mcal/kg)	3.34	3.33	3.33	3.34	3.34
Crude Protein (%)	17.39	15.89	14.30	13.09	12.16
Calcium (%)	0.49	0.51	0.53	0.52	0.52
Total Phosphate (%)	0.47	0.46	0.46	0.42	0.45
Lysine (%)	0.80	0.80	0.80	0.80	0.80
Methionine+cystine (%)	0.56	0.55	0.56	0.56	0.56
Threonine (%)	0.64	0.59	0.56	0.56	0.56
Lysine to protein ratio	4.6	5.0	5.6	6.1	6.6

[1] Provide the following nutrients per kilogram of complete diet; Vitamin A, 3000 IU; Vitamin D_3, 900 IU; Vitamin E_1, 9 IU; Vitamin K_3, 1.8 mg; Thiamine, 0.6 mg; Riboflavin,1.8 mg; Pyridoxine, 0.9 mg; Vitamin B_{12}, 6 ug; Niacin, 2 mg; Pantothenic acid, 7.2 mg; Folic acid, 200 mg; Fe, 35 mg; Cu, 31.25 mg; Zn, 43.75 mg; Mn, 14.9 mg; I, 0.96 mg; Se, 0.72 mg.

[2] All value was analyzed except DE, methionine + cystine, and tryptophan.

meal diets with 1.1% lysine on the growth performance of 5-20 kg pig, and found that the growth performance was not affected by dietary CP level (16.52% to 20.48% CP). Hansen and Lewic (1993) reported that when the amino acids composition of the diets was balanced, ADG of 5-20 kg pigs fed a diet containing 17% CP was higher than that of piglets fed a diet containing 21% CP ($p<0.06$); but the growth performance of piglets fed the diet with 15% CP was significantly lower than that of piglets fed the diet containing 21% CP, whether the dietary amino acid profile was balanced or not.

Pen et al. (1996) reported that when the lysine level in a low protein diet (containing 16% CP) was sufficient to meet the requirement of weanling pigs, growth performance was not affected by dietary protein levels; however, when the lysine level in a low protein diets was inadequate to meet the need of pigs, growth performance decreased. In our study, the lysine level in all diets (1.2% lysine) was sufficient to meet the growth requirement of pigs weighing 8-20 kg, so reduction of CP in the diet from 20.2% to 16.6% had no significant effect on the growth performance of pigs. Feed conversion efficiency was greatest and feed cost per gain was lowest for pigs fed the diet containing 5.8 g lysine/100 g CP. This result is similar to that reported by

Table 5. Effect of lysine to protein ratio on growth performance of 8-20 kg piglets (Trial one)

Item	Lysine to protein ratio (g/100 g)					Significant test	
	5.2	5.3	5.8	6.4	7.2	SEM	p value
Initial weight (kg)	9.08	9.06	9.05	8.99	9.13	0.61	1.00
Final weight (kg)	15.99	16.59	17.15	16.93	16.36	1.38	0.98
Average daily gain (kg)	0.33	0.36	0.39	0.38	0.35	0.04	0.86
Average daily feed intake (kg)	0.62	0.64	0.66	0.66	0.65	0.08	1.00
Feed / Gain	1.95	1.79	1.68	1.76	1.88	0.07	0.08
Feed cost (Yuan/kg)	1.99	1.97	1.97	2.01	2.05	-	-
Cost of each kilogram gain (Yuan/kg)	3.84	3.09	3.01	3.09	3.61	0.26	0.13

Note: means with different superscript in same row are significantly different ($p<0.05$).

Table 6. Effect of lysine to protein ratio on serum urea nitrogen and serum free amino acids concentrations for 8-20 kg piglets (Trial one)

	Lysine to protein ratio (g/100 g)					Significant test	
	5.2	5.3	5.8	6.4	7.2	SEM	p value
Serum urea nitrogen (mg/dL)	17.70[a]	16.39[a]	15.06[ab]	10.55[bc]	9.43[c]	1.53	0.01
Serum amino acids concentrations (mg/dL)							
Essential amino acids							
Threonine	6.93	7.82	8.08	8.57	7.85	0.62	0.46
Valine	3.18[b]	2.99[b]	2.97[b]	2.34[a]	2.33[a]	0.16	0.001
Methionine	0.62[ab]	0.46[a]	0.61[ab]	0.95[c]	0.89[bc]	0.11	0.02
Isoleucine	1.77	1.79	1.91	1.52	1.48	0.14	0.15
Leucine	3.19	2.74	2.89	2.59	2.81	0.21	0.35
Phenylalanine	1.90	1.69	1.89	1.84	1.63	0.15	0.63
Lysine	2.59[a]	3.21[a]	3.36[a]	3.72[ab]	5.01[b]	0.48	0.02
Histidne	1.31	1.26	1.36	1.31	1.14	0.13	0.80
Arginine	4.45	4.37	4.72	4.25	3.97	0.52	0.89
Non-essential amino acids							
Aspartic acid	0.73	0.77	0.64	0.66	0.66	0.10	0.90
Serine	1.85	2.02	2.36	1.79	1.64	0.20	0.13
Glutamic acid	4.11	3.69	4.59	5.08	4.95	0.75	0.67
Glycine	5.78	6.83	7.22	7.76	7.50	0.59	0.17
Alanine	3.53	3.38	3.96	3.93	4.18	0.51	0.80
Cystine	0.21	0.21	0.24	0.25	0.28	0.05	0.90
Tyrosine	3.15	3.36	3.08	2.62	2.74	0.29	0.38
Total amino acids	45.48	46.76	49.97	49.42	49.29	3.30	0.84

Note: means with different superscript in same row are significantly different ($p<0.05$).

Lin and Jensen (1996), who found that maximum gain/feed was achieved in weanling pigs fed a diet with 19.5% CP and 1.19% lysine.

Malmolf (1988) suggested the serum urea nitrogen could exactly reflect the metabolism of protein and the balance situation of amino acids in animal body. Research results demonstrated that the decrease in the dietary protein level with adding synthetic amino acids significantly reduced the serum urea nitrogen concentration (Fayuan, 1996). Both Trial one and two showed that as dietary CP levels decreased and the amino acid profile of the diet approached the ideal amino acids model, the serum urea nitrogen concentration gradually decreased and the utilization of dietary protein improved. Wutai (1997) reported that serum free amino acids content could reflect the metabolic situation of amino acids in the animal body. When a certain amino acid in diet was deficient, the serum free amino acid content was lower; when the diet met all the amino acids requirements of the animal, the improving the balance of dietary amino acids could further decrease the serum free amino acids content. The result of Trial one did not agree with the result reported by Wutai (1997). The reasons need to be studied further.

In our study, serum urea nitrogen and free amino acids concentrations were not used as the main criteria in determining the optimal ratio of lysine to protein because the number of plasma samples was limited. Instead, emphasis was placed on finding the optimal ratio of lysine to protein in a practical swine diet, as determined by growth performance and economic efficiency. In our trial using 8-20 kg pigs, the best average daily gain, the maximum feed conversion efficiency and economic efficiency was achieved with a diet lysine to protein ratio of 5.8 g/100 g. This is in agreement with the study of Zhengying (1994), in which the optimal ratio of lysine to protein in a diet including 1.2% lysine for 5-20 kg piglets was 6.0 g/100 g.

Trial two and Trial three were conducted to investigate the effect of lysine to protein ratio in diets including 1.1% and 0.8% lysine on efficiency of nitrogen retention and utilization in 20-60 kg and 60-80 kg pigs. In Trial two, when the lysine to protein ratio in diets increased from 5.2 to 6.8 g/100 g, dietary protein levels gradually decreased from 21.34% to 14.72%. Consequently, nitrogen retention declined linearly ($p=0.0011$). Apparent biological value and gross nitrogen efficiency increased linearly ($p=0.0135$ and $p=0.0192$, respectively) as dietary protein levels decreased. The results of our studies agree with those of Lee et al. (1998). They reported that nitrogen retention progressively increased ($p<0.01$), but apparent biological value declined ($p<0.05$) as dietary protein level increased from 14% to 17%. In trial two, with diets including 1.1% lysine, maxium nitrogen retention was achieved with a ratio of 5.2 g

Table 7. Effect of lysine to protein ratio on efficiency of nitrogen retention and utilization in 20-60 kg growing pigs (Trial two)

Item	Lysine to protein ratio (g/100 g)					Significant test	
	5.2	5.7	6.1	6.7	6.8	SEM	p value
Daily nitrogen flow							
Nitrogen Intake (g/day)	50.25^{a}	46.41^{ab}	41.80^{bc}	39.09^{c}	36.66^{c}	2.31	0.003
Fecal nitrogen (g/day)	4.81	4.33	3.50	3.87	3.61	0.54	0.43
Urinary nitrogen (g/day)	19.70^{a}	19.43^{ab}	16.80^{abc}	13.74^{bc}	11.40^{c}	1.98	0.03
Nitrogen retention (g/day)	25.75^{a}	22.64^{b}	21.50^{b}	21.48^{b}	21.66^{b}	0.78	0.004
Apparent biological value (%)	57.4	54.2	56.8	62.2	66.0	3.10	0.097
Gross nitrogen efficiency (%)	51.20	49.4	52.0	56.0	59.4	3.00	0.098
Apparent digestibility							
Dry matter (%)	90.0	91.0	91.0	90.0	90.0	1.00	0.95
Nitrogen (%)	90.4	90.8	91.4	90.0	90.4	1.00	0.95
Serum urea nitrogen (mg/dL)	17.00	16.80	15.60	11.20	10.80	2.05	0.10
Serum free lysine concentration (mg/dL)	2.53	2.45	1.94	2.45	2.90	0.43	0.65

Note: means with different superscript in the same row are significantly different ($p<0.05$).

Table 8. Effect of lysine to protein ratio on efficiency of nitrogen retention and utilization in 60-80 kg growing pigs (Trial three)

Item	Lysine to protein ratio (g/100 g)					Significant test	
	4.6	5.0	5.6	6.1	6.6	SEM	p value
Daily nitrogen flow							
Nitrogen Intake (g/day)	77.19^{a}	69.14^{b}	62.93^{c}	57.33^{d}	52.89^{e}	1.35	0.0000
Fecal nitrogen (g/day)	6.97	5.67	7.08	5.35	5.81	0.66	0.26
Urinary nitrogen (g/day)	40.44^{c}	30.61^{ab}	34.68^{cb}	30.45^{ab}	25.34^{a}	2.96	0.023
Nitrogen retention (g/day)	29.79^{ab}	32.86^{a}	21.17^{b}	21.53^{b}	21.71^{b}	3.05	0.033
Apparent biological value (%)	42.40	51.80	37.40	41.80	46.20	5.26	0.41
Gross nitrogen efficiency (%)	38.60	47.60	33.80	37.60	40.8	4.70	0.35
Apparent digestibility							
Dry matter (%)	88.6	90.2	87.6	89.8	88.8	0.99	0.40
Nitrogen (%)	91.2	91.8	88.6	90.4	88.8	1.00	0.13

Note: means with different superscript in the same row are significantly different ($p<0.05$).

lysine/100 g CP. The result was close to that of Wensheng (1984) and Lee et al (1998). Wensheng (1984) reported that when the lysine to protein ratio in 20-60 kg growing pig diets was 5.4 g/100 g, nitrogen retention was maximized at 42.2 g/day, which is higher than the maximum nitrogen retention of 25.75 g achieved in our study with a lysine to protein ratio of 5.2 g/100 g.

Lee et al (1998) reported that a concentration of 5.2 g lysine/100 g crude protein in the diet was more appropriate for corn-soybean diets than the commonly suggested 6.7 g lysine/100 g CP and that nitrogen retention was greatest when pigs were fed a practical diet with a concentration of 5.2 g lysine/100 g CP.

In Trial three, nitrogen retention declined linearly ($p=0.0099$) as protein levels in diets decreased. When the ratio of lysine to protein in the diet including 0.8% lysine was 5.0 g/100 g, nitrogen retention was greatest at 32.86 g/day, but apparent biological value and gross nitrogen efficiency did not change significantly as dietary protein levels decreased. Wensheng (1984) reported that when pigs weighing 60-90 kg were fed diets containing concentrations of 5.0 g lysine/100 g CP (14.5% CP and 0.73% lysine) and 5.2 g lysine/100 g CP (12% CP and 0.62% lysine), growth performance and efficiency of nitrogen retention were improved. In Trial two and three, apparent digestibility of DM and nitrogen in 20-40 kg and 60-80 kg growing pigs were not influenced by the ratio of lysine to protein (or CP levels) in the diets. The results agreed with those of Wensheng (1984).

IMPLICATIONS

In this study we found that for 8-20 kg pigs raised in the practical condition in China, the best daily gain and feed conversion efficiency, and the lowest feed cost were achieved with a diet containing 20.2% CP and 5.8 g lysine/100 g CP; nitrogen retention in 20-60 kg pigs was maximum in pigs fed a diet containing 21.34% CP and 5.2 g

lysine/100 g CP; and nitrogen retention in 60-80 kg pigs was maximum in pigs fed a diet containing 15.89% CP and 5.0 g lysine/100 g CP. Moreover, we concluded that nitrogen retention in growing pigs increased linearly with the decreasing lysine to protein ratio in a diet containing a given lysine level.

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