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Effects of Dietary Lysine and Energy Levels on Growth Performance and Apparent Total Tract Digestibility of Nutrients in Weanling Pigs

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ABSTRACT : Two experiments were conducted to determine the effects of dietary lysine and energy level on performance and apparent total tract digestibility (ATTD) of nutrients in weanling pigs. In Exp. 1, a total of 288 weaned pigs (initial BW 5.77±0.85 kg) were randomly allotted to 4 treatments (4 replicates per treatment with 18 pigs in each replicate). Experimental diets were fed in the 3 phases: phase I (d 0 to 7), phase II (d 8 to 14) and phase III (d 15 to 28). Isocalorific diets (3,450 kcal/kg) with incremental lysine levels (Phase I: 1.51, 1.61, 1.71 and 1.81; Phase II: 1.35, 1.46, 1.56 and 1.66; Phase III: 1.18, 1.28, 1.39 and 1.49% lysine respectively for T1, T2, T3 and T4) were used as treatments. An increase in the dietary lysine levels linearly improved ($p<0.05$) the ADG and G:F during phases I, II and III as well as overall study period. The ATTD of DM (d 7 and 28) and CP (d 7, 14 and 28) were linearly improved ($p<0.05$) with increasing dietary lysine levels. ATTD of ash, Ca and P were not affected by dietary lysine level. In Exp. 2, 64 weanling pigs (initial BW 4.79±0.79 kg) were randomly allotted to 4 treatments (4 replicates per treatment with 4 pigs in each replicate) in a 2×2 factorial arrangement on the basis of BW. Effects of two levels of energy (high, 3,450 or low, 3,350 kcal/kg) and lysine (high or low; 1.70 or 1.50, 1.55 or 1.35 and 1.40 or 1.20% in phase I, II and III diets, respectively) on performance and ATTD of nutrients were investigated. High energy and lysine diets improved ADG ($p<0.05$) in pigs during phase I, II and III and overall period ($p<0.001$), while G:F increased ($p<0.05$) during phase I and overall period. Pigs fed high lysine diets consumed more ($p<0.05$) feed during phase III and overall period. Additionally, pigs fed high energy diets had greater ($p<0.05$) ATTD of GE (d 7 and 14), CP (d 7 and 28) and DM (d 28); whereas, pigs fed high lysine diets had greater ($p<0.05$) ATTD of GE and CP during d 7, 14 and 28. ATTD of ash, Ca and P remained unaffected ($p>0.05$) by dietary energy and lysine level. However, there was no energy×lysine interaction for any of the measured variables. Results obtained in present study suggested that high energy and lysine level improve the growth performance and ATTD of nutrients in weanling pigs. (**Key Words :** Energy, Lysine, Apparent Total Tract Digestibility, Performance, Weanling Pigs)

INTRODUCTION

Feed intake and growth performance of growing pigs are determined by energy concentration of the diet (NRC, 1998). Therefore, amino acid requirement of growing pigs should be defined in relation to energy density of the diet. Lysine, the first limiting amino acid for growing pigs has been extensively investigated and reviewed (NRC, 1998). Several investigations on lysine requirement for weaned pigs have yielded variable results (Gatel et al., 1992; Nam and Aherne, 1994; Oresanya et al., 2007; Dneg et al., 2010). The lysine requirement for growing pigs is commonly expressed as lysine: energy ratio, which allows lysine requirements to be suitable for wide range of dietary energy (Main et al., 2008). Furthermore, dietary lysine requirement have been determined at only one dietary energy level (Martinez and Knabe, 1990). However, previous studies contain diverse estimates of the optimum lysine:energy for weaning pigs performing at levels commonly observed in commercial practice (Nam and Aherne, 1994; Smith et al., 1999; Urynek and Buraczewska, 2003; Oresanya et al., 2007; Schneider et al., 2010). Many factors, like genetic variation, nutrition, physiology, environment and management condition could be responsible for variation in requirement, in weanling pigs, but a major variation may be the interactive effects between energy density and lysine intake (Campbell and Dunkin, 1983; Zhang et al., 1984). With the economic importance of energy and amino acid source, the determination of the optimum lysine:energy to get a best performance in weaning pigs is badly needed. Therefore, objectives of these experiments were to

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investigate the effects of dietary lysine and energy levels on growth performance and apparent total tract digestibility of nutrients in weanling pigs.

MATERIALS AND METHODS

The protocol for the present experiments was approved by the Institutional Animal Care and Use Committee of Kangwon National University (Chunchon, Republic of Korea).

These experiments were conducted at the facility of Kangwon National University farm and the pigs (Landrace ×Yorkshire×Duroc) were housed in partially slotted and concrete floor pens with a pen size of 2.8 m×5.0 m. All pens were equipped with a self-feeder and nipple drinker to allow *ad libitum* access to feed and water.

Exp. 1

A total of 288 weaned pigs (Landrace×Yorkshire×Duroc, 21±2 d of age, average initial body weight 5.77±0.85 kg) were randomly allotted to 4 treatments on the basis of BW. Each treatment had 4 pens with 18 piglets in each pen. Experimental diets were fed in 3 phases, phase I (d 0 to 7; Table 1), phase II (d 8 to 14; Table 2) and phase III (d 15 to 28 Table 3). The four isocalorific (3,450 kcal/kg) diets with incremental lysine levels (phase I: 1.51, 1.61, 1.71 and 1.81; phase II: 1.35, 1.46, 1.56 and 1.66; phase III: 1.18, 1.28, 1.39 and 1.49% lysine respectively for T1, T2, T3 and T4) were used as treatments. All the diets met or exceeded the nutrient requirements as recommended by NRC (1998) and

Table 1. Composition of the basal diet (d 0-7; Exp. 1; as-fed basis)

Treatments	T1	T2	T3	T4
Ingredients (%)				
Corn	33.08	32.01	30.88	29.53
Fish meal (60%)	5.00	5.00	5.00	5.00
Whey powder	20.00	20.00	20.00	20.00
Deh-SBM	12.22	13.07	13.87	14.74
SPC	5.00	5.00	5.00	5.00
Soy oil	3.57	3.58	3.64	3.76
Lactose	12.00	12.00	12.00	12.00
SDPP (79%)	6.00	6.00	6.00	6.00
L-lysine (78%)	0.08	0.19	0.29	0.39
DL-methionine (100%)	0.21	0.26	0.33	0.39
Threonine (100%)	0.05	0.10	0.16	0.21
Tryptophan (10%)	-	-	0.05	0.21
Choline-chloride (50%)	0.05	0.05	0.05	0.05
Monocalcium phosphate	0.55	0.55	0.55	0.54
Limestone	0.89	0.89	0.88	0.88
ZnO	0.30	0.30	0.30	0.30
Apramycin (10%)	0.15	0.15	0.15	0.15
Salt	0.25	0.25	0.25	0.25
Mineral premix[1]	0.30	0.30	0.30	0.30
Vitamin premix[2]	0.30	0.30	0.30	0.30
Calculated composition				
ME (kcal/kg)	3,450	3,450	3,450	3,450
CP (%)	22.50	23.00	23.50	24.00
Ca (%)	0.90	0.90	0.90	0.90
Available P (%)	0.50	0.50	0.50	0.50
Lys (%)	1.51	1.61	1.71	1.81
AID Lys (%)	1.35	1.45	1.55	1.65
Met (%)	0.53	0.59	0.66	0.72
Thr (%)	1.04	1.11	1.18	1.24

T1, T2, T3 and T4: 1.51, 1.61, 1.71 and 1.81% lysine level respectively.
SPC = Soy protein concentrate; SDPP = Spray dried plasma protein.
[1] Supplied per kilogram of diet: 45 mg Fe, 0.25 mg Co, 50 mg Cu, 15 mg Mn, 25 mg Zn, 0.35 mg I, 0.13 mg Se.
[2] Supplied per kilogram of diet: 16,000 IU vitamin A, 3,000 IU vitamin D_3, 40 IU vitamin E, 5.0 mg vitamin K_3, 5.0 mg vitamin B_1, 20 mg vitamin B_2, 4 mg vitamin B_6, 0.08 mg vitamin B_{12}, 40 mg pantothenic acid, 75 mg niacin, 0.15 mg biotin, 0.65 mg folic acid, 12 mg antioxidant.

Table 2. Composition of the basal diet (d 7-14; Exp. 1; as-fed basis)

Treatments	T1	T2	T3	T4
Ingredients (%)				
Corn	42.37	41.20	39.85	38.53
Fish meal (60%)	5.00	5.00	5.00	5.00
Whey powder	15.00	15.00	15.00	15.00
Deh-SBM	19.81	20.64	21.51	22.32
SPC	5.00	5.00	5.00	5.00
Soy oil	4.15	4.22	4.35	4.48
Lactose	5.25	5.25	5.25	5.25
L-lysine (78%)	0.13	0.23	0.33	0.43
DL-methionine (100%)	0.14	0.19	0.25	0.31
Threonine (100%)	0.09	0.15	0.20	0.26
Tryptophan (10%)	-	0.07	0.23	0.39
Choline-chloride (50%)	0.05	0.05	0.05	0.05
MCP	0.96	0.96	0.95	0.95
Limestone	0.75	0.74	0.73	0.73
ZnO	0.30	0.30	0.30	0.30
Apramycin (10%)	0.15	0.15	0.15	0.15
Salt	0.25	0.25	0.25	0.25
Mineral premix[1]	0.30	0.30	0.30	0.30
Vitamin premix[2]	0.30	0.30	0.30	0.30
Calculated composition				
ME (kcal/kg)	3,450	3,450	3,450	3,450
CP (%)	21.50	22.00	22.50	23.00
Ca (%)	0.90	0.90	0.90	0.90
Available P (%)	0.50	0.50	0.50	0.50
Lys (%)	1.35	1.46	1.56	1.66
AID Lys (%)	1.20	1.30	1.40	1.50
Met (%)	0.49	0.54	0.60	0.67
Thr (%)	0.92	1.00	1.06	1.13
Trp (%)	0.25	0.27	0.29	0.31

T1, T2, T3 and T4: 1.35, 1.46, 1.56 and 1.66% lysine level respectively.

SPC = Soy protein concentrate; MCP = Monocalcium phosphate.

[1] Supplied per kilogram of diet: 45 mg Fe, 0.25 mg Co, 50 mg Cu, 15 mg Mn, 25 mg Zn, 0.35 mg I, 0.13 mg Se.

[2] Supplied per kilogram of diet: 16,000 IU vitamin A, 3,000 IU vitamin D_3, 40 IU vitamin E, 5.0 mg vitamin K_3, 5.0 mg vitamin B_1, 20 mg vitamin B_2, 4 mg vitamin B_6, 0.08 mg vitamin B_{12}, 40 mg pantothenic acid, 75 mg niacin, 0.15 mg biotin, 0.65 mg folic acid, 12 mg antioxidant.

Table 3. Composition of the basal diet (d 14-28; Exp. 1; as-fed basis)

Treatments	T1	T2	T3	T4
Ingredients (%)				
Corn	67.53	66.19	65.02	63.68
Fish meal (60%)	5.00	5.00	5.00	5.00
Deh-SBM	15.21	16.05	16.91	17.74
SPC	5.00	5.00	5.00	5.00
Soy oil	3.73	3.86	3.91	4.04
L-lysine (78%)	0.17	0.27	0.38	0.48
DL-methionine (100%)	0.09	0.15	0.20	0.26
Threonine (100%)	0.09	0.15	0.20	0.26
Tryptophan (10%)	0.06	0.22	0.28	0.45
Choline-chloride (50%)	0.05	0.05	0.05	0.05
MCP	0.96	0.96	0.95	0.95
Limestone	0.81	0.80	0.80	0.79
ZnO	0.30	0.30	0.30	0.30
Apramycin (10%)	0.15	0.15	0.15	0.15
Salt	0.25	0.25	0.25	0.25
Mineral premix[1]	0.30	0.30	0.30	0.30
Vitamin premix[2]	0.30	0.30	0.30	0.30
Calculated composition				
ME (kcal/kg)	3,450	3,450	3,450	3,450
CP (%)	19.50	20.00	20.50	21.00
Ca (%)	0.80	0.80	0.80	0.80
Available P (%)	0.40	0.40	0.40	0.40
Lys (%)	1.18	1.28	1.39	1.49
AID Lys (%)	1.05	1.15	1.25	1.35
Met (%)	0.42	0.48	0.54	0.60
Thr (%)	0.81	0.88	0.94	1.01
Trp (%)	0.21	0.24	0.25	0.27

T1, T2, T3 and T4: 1.18, 1.28, 1.39 and 1.49% lysine level respectively.

SPC = Soy protein concentrate; MCP = Monocalcium phosphate.

[1] Supplied per kilogram of diet: 45 mg Fe, 0.25 mg Co, 50 mg Cu, 15 mg Mn, 25 mg Zn, 0.35 mg I, 0.13 mg Se.

[2] Supplied per kilogram of diet: 16,000 IU vitamin A, 3,000 IU vitamin D_3, 40 IU vitamin E, 5.0 mg vitamin K_3, 5.0 mg vitamin B_1, 20 mg vitamin B_2, 4 mg vitamin B_6, 0.08 mg vitamin B_{12}, 40 mg pantothenic acid, 75 mg niacin, 0.15 mg biotin, 0.65 mg folic acid, 12 mg antioxidant.

differed in crude protein and lysine contents. The proportions of indispensable amino acids relative to lysine were above the balanced protein.

Exp. 2

A total of 64 weaned pigs (initial BW 4.79±0.79 kg) of mixed sex (48 males and 16 females) were randomly allotted to 4 treatments on the basis of BW in a 2×2 factorial arrangement. Each treatment had 4 pens with 4 pigs (3 males and 1 female) in each pen. Experimental diets were fed in 3 phases, phase I (d 0 to 7; Table 4), phase II (d 8 to 14; Table 5) and phase III (d 15 to 28 Table 6). Effects of two levels of energy (high, 3,450 or low, 3,350 kcal/kg) and lysine (high or low; 1.70 or 1.50, 1.55 or 1.35 and 1.40 or 1.20% in phase I, II and III diets, respectively) on performance and ATTD of nutrients were investigated. All the diets met or exceeded the nutrient requirements as recommended by NRC (1998) and differed in crude protein and lysine contents. The proportions of indispensable amino acids relative to lysine were above the balanced protein.

Experimental procedures, measurements and analyses

The pigs were weighed individually and feed consumption in each pen was measured at the end of each phase in both experiments. Growth performance in terms of average daily gain (ADG), average daily feed intake (ADFI) and gain:feed (G:F) was calculated during the feeding trial. To evaluate the effect of diets on the apparent total tract digestibility (ATTD) of energy and nutrients, 0.25% chromic oxide was included in the diets as an inert, indigestible indicator. The pigs were fed diets containing chromium during the last 7 d of each experiment, and fecal

Table 4. Composition of the basal diet (d 0-7; Exp. 2; as-fed basis)

ME, kcal/kg	3,350		3,450	
Lysine level (%)	1.50	1.70	1.50	1.70
Ingredients (%)				
Corn	36.63	32.02	34.22	29.59
Fish meal (60%)	5.00	5.00	5.00	5.00
Whey powder	20.00	20.00	20.00	20.00
Deh-SBM	10.76	15.32	11.18	15.75
SPC	5.00	5.00	5.00	5.00
Soy oil	1.55	1.50	3.54	3.49
SDPP (79%)	6.00	6.00	6.00	6.00
L-lysine (78%)	0.12	0.21	0.11	0.21
DL-methionine (100%)	0.14	0.20	0.14	0.21
Choline-chloride (50%)	0.05	0.05	0.05	0.05
MCP	0.55	0.53	0.56	0.53
Limestone	0.90	0.87	0.90	0.87
ZnO	0.30	0.30	0.30	0.30
Apramycin (10%)	0.15	0.15	0.15	0.15
Lactose	12.00	12.00	12.00	12.00
Salt	0.25	0.25	0.25	0.25
Mineral premix[1]	0.30	0.30	0.30	0.30
Vitamin premix[2]	0.30	0.30	0.30	0.30
Calculated composition (%)				
ME (kcal/kg)	3,350	3,350	3,450	3,450
CP (%)	22.00	23.93	22.00	23.93
Ca (%)	0.90	0.90	0.90	0.90
Av. P (%)	0.50	0.50	0.50	0.50
Lys (%)	1.50	1.70	1.50	1.70
AID Lys (%)	1.35	1.53	1.35	1.53
Met (%)	0.46	0.55	0.46	0.55
Thr (%)	0.97	1.04	0.97	1.05
Tryp (%)	0.28	0.31	0.28	0.31

SPC = Soy protein concentrate; SDPP = Spray dried plasma protein; MCP = Monocalcium phosphate.

[1] Supplied per kilogram of diet: 45 mg Fe, 0.25 mg Co, 50 mg Cu, 15 mg Mn, 25 mg Zn, 0.35 mg I, 0.13 mg Se.

[2] Supplied per kilogram of diet: 16,000 IU vitamin A, 3,000 IU vitamin D_3, 40 IU vitamin E, 5.0 mg vitamin K_3, 5.0 mg vitamin B_1, 20 mg vitamin B_2, 4 mg vitamin B_6, 0.08 mg vitamin B_{12}, 40 mg pantothenic acid, 75 mg niacin, 0.15 mg biotin, 0.65 mg folic acid, 12 mg antioxidant.

Table 5. Composition of the basal diet (d 7-14; Exp. 2; as-fed basis)

ME (kcal/kg)	3,350		3,450	
Lysine level (%)	1.35	1.55	1.35	1.55
Ingredients (%)				
Corn	49.11	41.87	46.70	39.46
Fish meal (60%)	5.00	5.00	5.00	5.00
Whey powder	15.00	15.00	15.00	15.00
Deh-SBM	14.97	22.33	15.39	22.75
SPC	5.00	5.00	5.00	5.00
Soy oil	2.13	2.07	4.12	4.06
L-lysine (78%)	0.29	0.28	0.28	0.27
DL-methionine (100%)	0.15	0.18	0.15	0.18
Choline-chloride (50%)	0.05	0.05	0.05	0.05
MCP	0.98	0.94	0.98	0.95
Limestone	0.77	0.73	0.78	0.73
ZnO	0.30	0.30	0.30	0.30
Apramycin (10%)	0.15	0.15	0.15	0.15
Lactose	5.25	5.25	5.25	5.25
Salt	0.25	0.25	0.25	0.25
Mineral premix[1]	0.30	0.30	0.30	0.30
Vitamin premix[2]	0.30	0.30	0.30	0.30
Calculated composition				
ME (kcal/kg)	3,350	3,350	3,450	3,450
CP (%)	19.80	22.73	19.80	22.73
Ca (%)	0.90	0.90	0.90	0.90
Av. P (%)	0.50	0.50	0.50	0.50
Lys (%)	1.35	1.55	1.35	1.55
AID Lys (%)	1.21	1.39	1.21	1.39
Met (%)	0.47	0.54	0.47	0.54
Thr (%)	0.77	0.88	0.77	0.88
Trp (%)	0.23	0.27	0.23	0.27

SPC = Soy protein concentrate; MCP = Monocalcium phosphate.

[1] Supplied per kilogram of diet: 45 mg Fe, 0.25 mg Co, 50 mg Cu, 15 mg Mn, 25 mg Zn, 0.35 mg I, 0.13 mg Se.

[2] Supplied per kilogram of diet: 16,000 IU vitamin A, 3,000 IU vitamin D_3, 40 IU vitamin E, 5.0 mg vitamin K_3, 5.0 mg vitamin B_1, 20 mg vitamin B_2, 4 mg vitamin B_6, 0.08 mg vitamin B_{12}, 40 mg pantothenic acid, 75 mg niacin, 0.15 mg biotin, 0.65 mg folic acid, 12 mg antioxidant.

Table 6. Composition of the basal diet (d 14-28; Exp. 2; as-fed basis)

ME (kcal/kg)	3,350		3,450	
Lysine level (%)	1.20	1.40	1.20	1.40
Ingredients (%)				
Corn	74.89	67.66	72.48	65.25
Fish meal (60%)	5.00	5.00	5.00	5.00
Deh-SBM	9.82	17.15	10.25	17.57
SPC	5.00	5.00	5.00	5.00
Soy oil	1.66	1.60	3.65	3.59
L-lysine (78%)	0.38	0.38	0.37	0.37
DL-methionine (100%)	0.08	0.12	0.08	0.13
Choline-chloride (50%)	0.05	0.05	0.05	0.05
MCP	0.98	0.95	0.98	0.95
Limestone	0.84	0.79	0.84	0.79
ZnO	0.30	0.30	0.30	0.30
Apramycin (10%)	0.15	0.15	0.15	0.15
Salt	0.25	0.25	0.25	0.25
Mineral premix[1]	0.30	0.30	0.30	0.30
Vitamin premix[2]	0.30	0.30	0.30	0.30
Calculated composition				
ME (kcal/kg)	3,350	3,350	3,450	3,450
CP (%)	17.60	20.53	17.60	20.53
Ca (%)	0.80	0.80	0.80	0.80
Av. P (%)	0.40	0.40	0.40	0.40
Total Lys (%)	1.20	1.40	1.20	1.40
AID Lys (%)	1.09	1.26	1.09	1.26
Met (%)	0.39	0.47	0.39	0.47
Thr (%)	0.64	0.75	0.64	0.75
Trp (%)	0.18	0.23	0.18	0.23

SPC = Soy protein concentrate; MCP = Monocalcium phosphate.

[1] Supplied per kilogram of diet: 45 mg Fe, 0.25 mg Co, 50 mg Cu, 15 mg Mn, 25 mg Zn, 0.35 mg I, 0.13 mg Se.

[2] Supplied per kilogram of diet: 16,000 IU vitamin A, 3,000 IU vitamin D_3, 40 IU vitamin E, 5.0 mg vitamin K_3, 5.0 mg vitamin B_1, 20 mg vitamin B_2, 4 mg vitamin B_6, 0.08 mg vitamin B_{12}, 40 mg pantothenic acid, 75 mg niacin, 0.15 mg biotin, 0.65 mg folic acid, 12 mg antioxidant.

grab samples were collected from the floor of each pen during the last 4 d. The fecal samples were pooled within pen and dried in an air-forced drying oven at 60°C for 72 h and ground with Wiley mill using a 1-mm screen for chemical analysis.

Feed samples of each experiment were collected from every batch, pooled and sub-samples were analysed for proximate chemical compositions. Analysis of experimental diets and excreta was done according to the method of AOAC (1990). Gross energy was measured by a bomb calorimeter (Model 1261, Parr Instrument Co., Moline, IL), and chromium concentration was determined with an automated spectrophotometer (Jasco V-650, Jasco Corp., Tokyo, Japan) according to the procedure of Fenton and Fenton (1979). Amino acid composition of feed samples was determined by HPLC (Waters 486, Waters Corp., Milford, MA) following acid hydrolysis. Methionine and Cys were determined following oxidation with performic acid (Moore, 1963).

Statistical analyses

The data for Exp. 1 were analysed by using the general linear model (GLM) procedure of SAS software (1996). The treatments were the main effects. Pen was used as the experimental unit for the analysis of all the parameters. Linear and quadratic polynomials were evaluated for increasing lysine levels, and the mean separations were analyzed using the Duncan's multiple range test. In Exp. 2, data was analysed by GLM procedure of SAS software (1996) with a 2×2 factorial design contrast. The treatments were the main effects. Pens were used as the experimental unit for the analysis of all the parameters. The p-values compared the differences between the energy levels, lysine levels, and their interaction. Differences were considered statistically significant at $p<0.05$.

RESULTS AND DISCUSSION

In Exp. 1, during phase I, II and III as well as overall study period, increase in dietary lysine levels linearly improved ($p<0.05$; Table 7) ADG and lysine intake. Pig fed diet with increasing lysine level showed increase (Linear, $p<0.05$) in G:F. Results obtained in present study are in good agreement with findings of Schneider et al. (2010) in

Table 7. Effects of dietary lysine levels on growth performance of weaning pig (Exp. 1)

Item	T1	T2	T3	T4	SEM[1]	p-value	
						Linear	Quadratic
d 0-7 (Phase I)							
ADG (g)	233[b]	237[ab]	243[ab]	244[a]	1.93	0.019	0.671
ADFI (g)	289	291	293	295	1.76	0.253	0.951
G/F	0.81	0.81	0.83	0.83	0.01	0.026	0.451
Lys intake (g/d)	4.37[d]	4.69[c]	5.01[b]	5.35[a]	0.10	<0.001	0.901
AID Lys intake (g/d)	3.91[d]	4.22[c]	4.54[b]	4.87[a]	0.10	<0.001	0.896
d 8-14 (Phase II)							
ADG (g)	269[c]	273[bc]	279[ab]	281[a]	1.58	0.001	0.812
ADFI (g)	370	373	372	378	1.80	0.149	0.645
G/F	0.73	0.73	0.75	0.74	0.01	0.026	0.376
Lys intake (g/d)	4.99[d]	5.44[c]	5.80[b]	6.28[a]	0.12	<0.001	0.801
AID Lys intake (g/d)	4.43[d]	4.85[c]	5.20[b]	5.67[a]	0.12	<0.001	0.548
d15-28 (Phase III)							
ADG (g)	381[b]	386[b]	392[a]	394[a]	1.48	<0.001	0.320
ADFI (g)	627	624	613	621	2.58	0.171	0.257
G/F	0.61	0.62	0.64	0.63	0.01	<0.001	0.076
Lys intake (g/d)	7.40[d]	7.99[c]	8.51[b]	9.25[a]	0.18	<0.001	0.270
AID Lys intake (g/d)	6.59[d]	7.18[c]	7.66[c]	8.38[a]	0.17	<0.001	0.272
d 0-28 (Overall)							
ADG (g)	318[c]	322[b]	328[a]	330[a]	1.29	<0.001	0.271
ADFI (g)	485	477	476	483	2.37	0.719	0.177
G/F	0.66	0.67	0.69	0.68	0.01	0.011	0.113
Lys intake (g/d)	5.59[d]	6.04[c]	6.44[b]	6.96[a]	0.13	<0.001	0.206
AID Lys intake (g/d)	4.98[d]	5.41[c]	5.80[b]	6.31[a]	0.13	<0.001	0.136

T1 = 1.51, 1.35 and 1.18; T2 = 1.61, 1.46 and 1.28; T3 = 1.71, 1.56 and 1.39; T4 = 1.81, 1.66 and 1.49% lysine, respectively, in phase I, II, and III diets.
[abcd] Values with different superscripts in the same row differ significantly ($p<0.05$).
[1] SEM = Standard error of means.

nursery pigs, in which increase in dietary lysine level from 0.99 to 1.30% showed linear increase in ADG, lysine intake and G:F. Similarly, increasing the dietary lysine level from 1.4 to 1.8% resulted into 10% improvement in ADG of pigs (Owen et al., 1994). Lenehan et al. (2003) reported higher ADG and G:F in pigs fed 1.4% of lysine. In present study there was no effect of dietary lysine level on ADFI of weanling pig. Similar ADFI responses were reported by Campbell and Taverner (1988), who found no difference in voluntary feed intake of pig fed iso-calorific diets varying in lysine content. Zhang et al. (2008) and Schneider et al. (2010) also reported no influence of dietary lysine level on ADFI in pigs. In contrast, Smith et al. (1999) observed decreasing ADFI as the energy density of diets was increased. This variation in feed intake might be due to variation in the energy density of the diet, as feed intake by growing pigs is generally determined by energy density of the diet (NRC, 1998).

In Exp. 2, Pigs fed high energy and high lysine diets had greater ($p<0.05$; Table 8) ADG during phase I, II and III as well as overall study period. Pigs fed high lysine diets showed increased ($p<0.05$) ADFI during phase II, III and overall study period. Additionally, high energy (phase I and overall study period) and high lysine (phase I, II, III and overall study period) diets improved ($p<0.05$) the G:F. Increased growth performance with increase in dietary energy and lysine level in present study are consistent with other reports in the literature (Nam and Aherne, 1994; Smith et al., 1999; Oresanya et al., 2007). Lawrence et al. (1994) reported increased growth performance in growing pigs in response to increase in dietary lysine:energy. Castle et al. (1994) also observed improved ADG and G:F when lysine:energy was increased from 1.35 to 2.59 g lysine/Mcal DE. Some other studies also reported increase in lysine:energy in growing pig diets improved ADG and G:F (Rao and McCracken, 1990; Chiba et al., 1991). Increase in lysine and energy level in present study showed increase in total and AID lysine intake ($p<0.05$) during all three phases

Table 8. Effects of dietary energy and lysine levels on growth performance of weaning pigs (Exp. 2)

ME, kcal/kg	3,350		3,450		SEM[1]	p-value[2]		
Lysine level	Low	High	Low	High		EL	LL	EL×LL
d 0-7 (Phase I)								
ADG, g	202	207	207	223	2.90	0.042	0.036	0.233
ADFI, g	264	261	263	269	3.17	0.594	0.818	0.503
G/F	0.77	0.80	0.79	0.83	0.01	0.044	0.012	0.526
Lys intake, g/d	3.96	4.43	3.94	4.57	0.09	0.564	<0.001	0.481
AID Lys intake, g/d	3.56	3.99	3.55	4.12	0.08	0.564	<0.001	0.481
d 14 (Phase II)								
ADG, g	230	252	237	267	4.33	0.047	<0.001	0.476
ADFI, g	317	341	322	349	5.01	0.462	0.012	0.870
G/F	0.72	0.74	0.74	0.77	0.01	0.076	0.038	0.493
Lys intake, g/d	4.28	5.28	4.35	5.40	0.14	0.470	<0.001	0.836
AID Lys intake, g/d	3.84	4.74	3.90	4.84	0.13	0.470	<0.001	0.836
d 8-14 (Phase II)								
ADG, g	348	365	357	380	3.76	0.041	0.002	0.068
ADFI, g	572	583	578	592	3.01	0.190	0.039	0.720
G/F	0.61	0.63	0.62	0.64	0.01	0.064	0.004	0.524
Lys intake, g/d	6.86	8.16	6.93	8.28	0.17	0.197	<0.001	0.716
AID Lys intake, g/d	6.23	7.34	6.30	7.45	0.15	0.197	<0.001	0.720
d 0-28 (Overall)								
ADG, g	290	306	298	322	3.20	<0.001	<0.001	0.084
ADFI, g	443	454	447	463	2.43	0.067	0.001	0.482
G/F	0.66	0.68	0.67	0.70	0.01	0.004	<0.001	0.248
Lys intake, g/d	5.03	5.96	5.08	6.09	0.13	0.085	<0.001	0.349
AID Lys intake, g/d	4.54	5.36	4.58	5.47	0.11	0.085	<0.001	0.350

[1] SEM = Standard error of means.

[2] EL = Energy level (high, 3,450 or low, 3,350 kcal/kg); LL = Lysine level (high or low; 1.70 or 1.50, 1.55 or 1.35 and 1.40 or 1.20% in phase I, II and III diets, respectively); EL×LL = Energy level×lysine level interaction.

as well as overall period of experimental feeding. Schneider et al. (2010) observed increased lysine intake with increase in dietary lysine level but reduced lysine intake with increase in energy density of diet. In this study, no interaction effect among energy and lysine levels on any of the growth performance parameters and lysine intake were detected. These findings are in good agreement with Nam and Aherne (1994) who also did not report interaction effect among energy and lysine levels on growth performance in weaning pigs. Similarly, Urynek and Buraczewska (2003) also reported no interaction between energy and lysine levels on growth performance of weaned pigs from 9.1 to 25.7 kg BW. Contrary to present findings, Van Lunen and Cole (2001) reported a DE×lysine:DE interaction on growth performance in weaned pigs. Smith et al. (1999) also detected interaction between ME×lysine:ME on growth performance of weaned pig from 10 to 25 kg body weight. Variable performance of pigs among studies might be due to variation in age of pigs, environment and management conditions. Improvement in management, health status and genetic growth potential suggest that existing (NRC, 1998) recommendations of lysine:energy are not sufficient for optimal growth performance in growing pigs.

In Exp. 1, The ATTD of DM (d 7 and 28) and CP (d 7, 14 and 28) were linearly improved (p<0.05; Table 9) with increasing dietary lysine level. Additionally, pigs fed T3 and T4 diets had greater digestibility of DM (d 7 and 28) and CP (d 7, 14 and 28 compared with pigs fed T1 diet. There were no effect of dietary lysine level on ATTD of ash, Ca and P. Similar to present finding, Jin et al. (2010) observed higher digestibility of CP in pigs fed high lysine diet. Cho et al. (2008) also reported increase in CP digestibility with increase in lysine content of diet but no effect on DM, ash, Ca and P digestibility. In contrast, Noblet et al. (1987) demonstrated that lysine addition in low protein diet did not affect protein digestibility. In Exp. 2, pigs fed high energy diet had greater (p<0.05; Table 10) ATTD of GE (d 7 and 14), CP (d 7 and 28) and DM (d 28); whereas, pigs fed high lysine diets had greater (p<0.05) ATTD of GE and CP during d 7, 14 and 28. However, there was no energy level×lysine level interaction effect (p>0.05) on the ATTD of nutrients. Results obtained herein are in good agreements with Lawrence et al. (1994), who reported increase in ATTD of DM and energy with increase in energy density of diet. Increase in energy density and lysine:energy in diet resulted into increase in CP

Table 9. Effect of increasing lysine level on apparent total tract digestibility (%) of nutrients in weaning pig (Exp. 1)

Item	T1	T2	T3	T4	SEM[1]	p-value	
						Linear	Quadratic
d 7 (Phase I)							
DM	87.90[c]	88.00[bc]	88.38[a]	88.20[ab]	0.08	0.002	0.067
GE	86.25	86.39	86.64	86.44	0.08	0.077	0.103
CP	78.03[b]	78.15[b]	78.57[a]	78.75[a]	0.22	<0.001	0.786
Ash	56.94	57.82	57.14	57.86	0.29	0.453	0.896
Ca	60.09	60.17	60.11	60.31	0.22	0.793	0.907
P	58.96	58.55	59.05	59.10	0.19	0.619	0.589
d 14 (Phase II)							
DM	86.30	86.58	86.52	86.65	0.07	0.144	0.613
GE	84.91	85.03	85.14	85.12	0.05	0.148	0.494
CP	76.01[b]	76.34[ab]	76.34[a]	76.68[a]	0.11	0.020	0.452
Ash	53.70	54.37	54.27	54.16	0.46	0.781	0.706
Ca	56.42	56.29	56.48	56.57	0.36	0.857	0.896
P	51.63	52.10	52.35	52.37	0.27	0.354	0.698
d 28 (Phase III)							
DM	86.93[b]	86.99[b]	87.38[a]	87.35[a]	0.07	0.003	0.651
GE	86.03	86.07	86.18	86.19	0.04	0.177	0.880
CP	74.83[b]	75.05[ab]	75.25[a]	75.28[a]	0.07	0.012	0.438
Ash	50.10	51.16	50.69	51.28	0.39	0.424	0.782
Ca	57.80	57.60	57.63	57.75	0.19	0.950	0.700
P	53.77	53.80	53.44	53.54	0.26	0.691	0.953

T1 = 1.51, 1.35 and 1.18; T2 = 1.61, 1.46 and 1.28; T3 = 1.71, 1.56 and 1.39; T4 = 1.81, 1.66 and 1.49% lysine, respectively, in phase I, II, and III diets.
[abc] Values with different superscripts in the same row differ significantly (p<0.05).
[1] SEM = Standard error of means.

Table 10. Effects of dietary energy and lysine levels on apparent total tract digestibility (%) of nutrients in weaning pigs (Exp. 2)

ME (kcal/kg)	3,350		3,450		SEM[1]	p-value[2]		
Lysine level	Low	High	Low	High		EL	LL	EL×LL
d 7 (Phase I)								
DM	87.63	87.66	87.75	87.69	0.04	0.336	0.834	0.576
GE	86.19	86.36	86.35	86.48	0.04	0.032	0.022	0.785
CP	77.25	77.39	77.33	77.41	0.07	0.044	0.041	0.722
Ash	57.61	57.95	57.84	58.36	0.26	0.576	0.460	0.873
Ca	63.05	63.83	63.76	63.85	0.13	0.103	0.052	0.121
P	55.41	55.88	55.86	56.01	0.15	0.368	0.329	0.615
d 14 (Phase II)								
DM	85.72	85.88	85.79	86.24	0.08	0.181	0.066	0.360
GE	83.49	84.75	84.57	85.20	0.18	0.001	<0.001	0.089
CP	78.44	79.77	78.35	79.96	0.21	0.790	<0.001	0.514
Ash	61.66	60.82	61.77	62.03	0.27	0.251	0.598	0.334
Ca	59.19	58.05	59.92	59.97	0.44	0.152	0.537	0.505
P	51.53	49.82	52.44	52.79	0.61	0.128	0.577	0.405
d 28 (Phase III)								
DM	86.24	86.33	86.39	86.66	0.06	0.024	0.073	0.358
GE	86.03	86.22	86.10	86.51	0.07	0.147	0.023	0.375
CP	81.34	82.42	82.12	82.84	0.16	0.002	<0.001	0.266
Ash	54.28	53.51	54.03	54.25	0.36	0.760	0.732	0.545
Ca	61.64	60.69	61.32	62.28	0.26	0.210	0.996	0.068
P	57.93	59.99	56.83	57.77	0.38	0.808	0.742	0.982

[1] SEM = Standard error of means.
[2] EL = Energy level (high, 3,450 or low, 3,350 kcal/kg); LL = Lysine level (high or low; 1.70 or 1.50, 1.55 or 1.35 and 1.40 or 1.20% in phase I, II and III diets, respectively); EL×LL = Energy level×lysine level interaction.

digestibility but no effect on DM digestibility (Cho et al., 2008). In various previous studies, determinations of apparent fecal and ileal digestibility were carried out at different dietary amino acid levels (Holmes et al., 1974; Jorgensen et al., 1984; Knabe et al., 1989). The results from these studies did not allow the establishment of a detailed relationship between the lysine:energy and apparent digestibility. However in present study digestibility of dry matter and crude protein increased linearly with increase in lysine level of diet and digestibility of gross energy and crude protein showed improvement with increase in lysine and energy density of diet. Understanding the effect of increasing dietary lysine and energy is a most important issue in developing cost-effective feeding strategies. Although lysine and energy requirement of pigs have been well studied, genetics and environment and management may affect an optimum lysine and energy regimen. Present study showed that 1.4% lysine and 3,450 kal ME/kg showed higher growth performance and ATTD of nutrients in weanling pigs.

In conclusion, results obtained in present study suggest that increase in dietary lysine and energy levels shows improvement in growth performance and apparent total tract digestibility of nutrients.

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