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Digestible lysine levels in low-protein diets supplemented with synthetic amino acids for nursery, growing, and finishing barrows

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To investigate the effect of lysine level in low-protein diets (LPD) an experiment was conducted with 36 barrows fed 174, 140 and 118 g/kg of crude protein (CP), and three digestible lysine levels. Low-protein diets were supplemented with crystalline amino acids (AA) to the same concentration as in the standard CP diet. Growth performance, carcass characteristics and plasma urea nitrogen concentration were evaluated. In nursery pigs, the addition of lysine to LPD quadratically increased backfat thickness (BF; $P<0.01$), *longissimus* muscle area (LMA; $P<0.001$), and lean meat percentage (LMP; $P<0.05$). In the growing phase, reducing dietary protein decreased average daily gain (ADG; $P<0.09$), final body weight (BW; $P<0.09$), fat free lean gain (FFLG; $P<0.09$), and LMA ($P<0.038$); and increased BF ($P<0.05$). Addition of lysine to LPD quadratically increased ADG ($P<0.01$), average daily feed intake (ADFI; $P<0.05$), final BW ($P<0.006$), and FFLG ($P<0.002$). In the finishing period, pigs fed LPD had lower ADFI ($P<0.03$) and feed:gain ratio (FGR; $P<0.003$). Addition of lysine to LPD linearly increased BF ($P<0.04$), and quadratically increased ADFI ($P<0.02$), FGR ($P<0.009$), BF ($P<0.08$), and LMA ($P<0.08$). The plasma urea nitrogen concentration was reduced ($P<0.05$) in all phases in pigs fed LPD. Lysine requirement for fattening barrows fed LPD may be higher than the recommended concentration for standard CP diets.

Keywords: low-protein diets; lysine levels; pigs; plasma urea nitrogen concentration

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Introduction

The genetic potential for leanness has increased in pigs and this has increased their lysine requirement (Friesen *et al*. 1994). Fulfillment of this requirement depends on the response criterion used to determine it, such as growth performance, carcass characteristics, or muscle protein retention rate; and on the type of diet fed to pigs (NRC 1998).

When pigs are fed a low-protein, amino acid (AA)-supplemented diet, it is possible to get a similar response as in pigs fed a standard crude protein (CP) diet, even when CP is reduced from 205 to 160 g/kg in sorghum-soybean meal diets for nursery pigs (Trujillo *et al*. 2007); from 165 to 145 g/kg in growing pigs (Martínez-Aispuro *et al*. 2009), and from 140 to 115 g/kg in the finishing phase (Figueroa *et al*. 2008). However, in other research (Powell *et al*. 2011), pigs fed AA-supplemented LPD responded with lower growth performance, maybe due to a reduction in the nutrient concentration in the diets, such as non-essential AA.

Low-protein diets (LPD) should be accompanied by proper supplementation of synthetic AA, to reduce the energy loss due to lower nitrogen excretion as urea and body heat (Le Bellego *et al*. 2001) and to reduce nitrogen concentration in swine excreta without affecting the response of pigs. Low-protein diets may increase the body fat in pigs (Tuitoek *et al*. 1997). This could be prevented by increasing the lysine levels in LPD based on sorghum-soybean because this lysine is the first limiting AA in such diets (Wiltafsky *et al*. 2009).

The objective of this study was to evaluate the effect of higher digestible lysine levels in sorghum-soybean meal LPD for nursery, growing, and finishing pigs, on the growth performance, carcass characteristics, and plasma urea nitrogen concentration.

Materials and Methods

The experimental procedures were performed according to the recommendations of the International Guiding Principles for Biomedical Research Involving Animals (CIOMS 1986), and complied with Mexican law (NOM-062-Z00-1999) for the use of animals in experimentation (DOF 2001).

Animals, experimental design and diets

Thirty six hybrid (Landrace × Yorkshire × Pietrain) barrows (10.58±1.42 kg initial body weight) were used and fed two levels of CP (standard = T0: 205, 165, and 140 g/kg for nursery, growing and finishing pigs, respectively; and LPD = 174, 140, and 118 g/kg CP in nursery, growing, and finishing phases, respectively) and three levels of digestible lysine in LPD (10.1, 11.1, and 12.1 g/kg in nursery; 8.3, 9.3, and 10.3 g/kg in growing; and 6.6, 7.6, and 8.6 g/kg in finishing stage; T1, T2, and T3, respectively, in each phase of growth; Tables 1–3) in a completely randomized design (Littell *et al*. 2004), with 10 replicates per treatment (six replicates for control diet). Each pig was individually housed in a 1.2×1.5 m, concrete floor pen, equipped with a single feeder and a nipple waterer. The experimental diets were based on sorghum-soybean meal. All diets were formulated to the same metabolisable energy (ME) concentration (13.66 MJ/kg). The LPD were supplemented with crystalline AA [L-lysine·HCl (Ajinomoto Eurolysine S.A.S., Paris Cedex, France), L-threonine (ADM Co., Decatur, IL, USA), DL-methionine (DEGUSSA Co., Parsippany, NJ, USA), and L-tryptophan (Ajinomoto Eurolysine S.A.S., Paris

Table 1. Standard and experimental low-protein diets for nursery pigs

Type of diet	Standard	Low-protein		
Crude protein (g/kg)	205	174	174	174
Ingredient (g/kg); Lysine (g/kg)	10.1	10.1	11.1	12.1
Soybean meal (44% crude protein)	334.00	235.00	232.50	227.50
Sorghum grain	624.10	715.85	715.70	718.50
Dicalcium phosphate	12.05	13.75	14.00	14.00
Calcium carbonate	8.15	7.85	7.75	7.75
L-lysine·HCl	0.75	3.75	5.25	6.50
L-threonine	0.00	1.00	1.10	1.10
DL-methionine	0.20	1.05	1.10	1.15
Salt	3.50	3.50	3.50	3.50
Soybean oil	14.25	15.25	16.10	17.00
Vitamin premix[1]	1.00	1.00	1.00	1.00
Trace mineral premix[2]	1.00	1.00	1.00	1.00
Oxytetracycline	1.00	1.00	1.00	1.00
Estimated analysis (g/kg) as fed				
Metabolizable energy (MJ/kg)	13.66	13.66	13.66	13.66
Crude protein	205	174	174	174
Calcium	7.0	7.0	7.0	7.0
Available phosphorus	3.4	3.5	3.6	3.6
Total phosphorus	6.0	6.0	6.0	6.0
Lysine	10.1	10.1	11.1	12.1
Threonine	6.5	6.3	6.4	6.3
Tryptophan	2.3	1.8	1.8	1.8
Methionine + cystine	5.8	5.8	5.8	5.8
Arginine	12.1	9.4	9.3	9.2
Histidine	4.7	3.8	3.8	3.8
Isoleucine	7.8	6.4	6.4	6.3
Leucine	16.9	14.9	14.8	14.7
Valine	8.4	7.0	7.0	6.9
Phenylalanine + tyrosine	16.1	13.4	13.3	13.2
Determined content (g/kg) as fed				
Crude protein	213	171	177	175
Calcium	7.5	7.9	7.9	7.8
Total phosphorus	5.7	5.0	5.5	5.8
Cost of diet (€/kg)[3]	0.26	0.25	0.25	0.25

[1]Supplied per kg of feed: vitamin A, 15,000 IU; vitamin D3, 2500 IU; vitamin E, 37.5 IU; vitamin K, 2.5 mg; thiamine, 2.25 mg; riboflavin, 6.25 mg; niacin, 50 mg; pyridoxine, 2.5 mg; cyanocobalamine, 0.0375 mg; biotin, 0.13 mg; choline chloride, 563 mg; pantothenic acid, 20 mg; folic acid, 1.25 mg.
[2]Supplied per kg of feed: Fe, 150 mg; Zn, 150 mg; Mn, 150 mg; Cu, 10 mg; Se, 0.15 mg; I, 0.9 mg; Cr, 0.2 mg.
[3]Calculated with the cost of ingredients in September–November 2010. Converted to euro (€) with the rate exchange of March 20, 2012 (17.151 Mexican pesos/€).

Cedex, France] to equal the concentration of lysine, threonine, methionine, and tryptophan of the control diet (T0) for each stage of growth. Food and water were provided *ad libitum*. The experiment lasted 21 days in the nursery, 35 days in the growing, and 56 days in the finishing (consecutive) phases, respectively.

Experimental procedure

Body weight, to calculate the average daily gain (ADG), as well as the average

Table 2. Standard and experimental low-protein diets for growing pigs

Type of diet	Standard		Low-protein	
Crude protein (g/kg)	165	140	140	140
Ingredient (g/kg); Lysine (g/kg)	8.3	8.3	9.3	10.3
Soybean meal (44% crude protein)	213.00	135.00	132.50	130.00
Sorghum grain	755.95	827.46	827.65	827.80
Dicalcium phosphate	7.35	8.25	8.25	8.25
Calcium carbonate	9.10	9.20	9.25	9.25
L-lysine·HCl	2.05	4.40	5.75	7.15
Tryptophan	0.00	0.40	0.40	0.40
L-threonine	0.15	1.10	1.15	1.15
DL-methionine	0.10	0.80	0.80	0.85
Salt	2.50	2.50	2.50	2.50
Soybean oil	7.80	8.90	9.75	10.65
Vitamin premix[1]	1.00	1.00	1.00	1.00
Trace mineral premix[2]	1.00	1.00	1.00	1.00
Estimated analysis (g/kg) as fed				
Metabolizable energy (MJ/kg)	13.66	13.66	13.66	13.66
Crude protein	165	140	140	140
Calcium	6.0	6.0	6.0	6.0
Available phosphorus	2.3	2.3	2.3	2.3
Total phosphorus	4.8	4.7	4.7	4.6
Lysine	8.3	8.3	9.3	10.3
Threonine	5.2	5.2	5.2	5.2
Tryptophan	1.8	1.8	1.8	1.8
Methionine+cystine	4.7	4.7	4.7	4.7
Arginine	8.9	6.8	6.7	6.6
Histidine	3.7	3.0	3.0	2.9
Isoleucine	6.1	5.0	5.0	4.9
Leucine	14.6	13.1	13.0	12.9
Valine	6.8	5.7	5.7	5.6
Phenylalanine+tyrosine	12.9	10.8	10.7	10.6
Determined content (g/kg) as fed			.	
Crude protein	162.1	130.2	137.0	135.0
Calcium	8.8	7.6	7.8	7.9
Total phosphorus	4.9	4.8	4.9	4.8
Cost of diet (€/kg)[3]	0.22	0.21	0.21	0.21

See footnotes to Table 1.

daily feed intake (ADFI) and feed:gain ratio (FGR) were determined weekly. On the last day of each period, blood samples were taken by venipuncture of the vena cava using heparinized vacutainer tubes (BD Vacutainer, Franklin Lakes, NJ 07417, USA); blood samples were held on ice until centrifuged at 2.500 rpm (1.286 *g*) for 20 min (IEC Centra 8R, International Equipment Company, USA) to separate plasma from cellular components. Once separated, the plasma was transferred to polypropylene tubes and stored at –20 °C (EUR251P7W Tappan, Electrolux Home Products North America, USA) until the determination of plasma urea N (PUN) by UV spectrophotometry (Spectrophotometer Cary 1E UV-vis, Varian, Australia; Chaney and Marbach 1962).

Table 3. Standard and experimental low-protein diets for finishing pigs

Type of diet	Standard	Low-protein		
Crude protein (g/kg)	140	118	118	118
Ingredient (g/kg); Lysine (g/kg)	6.6	6.6	7.6	8.6
Soybean meal (44% crude protein)	140.00	70.00	67.50	65.00
Sorghum grain	836.00	900.70	900.80	900.65
Dicalcium phosphate	6.00	6.50	6.50	6.75
Calcium carbonate	7.80	8.10	8.10	8.00
L-lysine·HCl	2.05	4.15	5.50	6.90
L-tryptophan	0.00	0.30	0.30	0.30
L-threonine	0.10	0.95	1.00	1.05
DL-methionine	0.00	0.50	0.55	0.60
Salt	2.50	2.50	2.50	2.50
Soybean oil	3.55	4.30	5.25	6.25
Vitamin premix[1]	1.00	1.00	1.00	1.00
Trace mineral premix[2]	1.00	1.00	1.00	1.00
Estimated analysis (g/kg) as fed				
Metabolizable energy (MJ/kg)	13.66	13.66	13.66	13.66
Crude protein	140.0	118.0	118.0	118.0
Calcium	5.0	5.0	5.0	5.0
Available phosphorus	1.9	1.9	1.9	1.9
Total phosphorus	4.3	4.2	4.1	4.2
Lysine	6.6	6.6	7.6	8.6
Threonine	4.3	4.3	4.3	4.3
Tryptophan	1.4	1.4	1.4	1.4
Methionine+cystine	4.0	3.9	3.9	3.9
Arginine	7.0	5.1	5.0	4.9
Histidine	3.1	2.4	2.4	2.4
Isoleucine	5.1	4.1	4.1	4.0
Leucine	13.3	11.9	11.8	11.8
Valine	5.8	4.8	4.8	4.8
Phenylalanine+tyrosine	11.0	9.1	9.0	8.9
Determined content (g/kg) as fed				
Crude protein	147.0	120.2	121.0	120.0
Calcium	7.1	6.8	6.7	6.9
Total phosphorus	3.9	3.6	3.9	3.7
Cost of diet (€/kg)[3]	0.19	0.19	0.19	0.19

See footnotes to Table 1.

On the first and last day of each period of fattening, backfat (BF) thickness and *longissimus* muscle area (LMA) were measured at the 10th rib using real time ultrasound (Sonovet 600, Medison Inc., Cypress, California, USA). These data, together with the initial and final weights were used to calculate the fat free lean gain (FFLG), and lean meat percentage (LMP), using the National Pork Producers Council (NPPC 1991) equation. The following determinations on rations were performed: CP by Kjeldahl method (AOAC 1990); gross energy (GE) in an adiabatic bomb calorimeter (Oxygen Bomb Calorimeter, Parr Instruments Company, Illinois, USA; Tejada 1992); the concentration of Ca by atomic absorption spectrophotometry (Spectrophotometer Varian SpectrAA 10 plus, Varian, Australia); and P by UV spectrophotometry (Spectrophotometer

Varian Cary 1E UV-vis, Varian, Australia; Fick *et al*. 1979).

Statistical analysis
The data were analyzed using the GLM procedure of SAS (1999) with initial body weight of each phase as a covariate for all variables; comparison of means was performed with the following specific contrasts: standard CP (T0) *vs.* LPD (T1); as well as linear and quadratic orthogonal contrasts for lysine levels in LPD (T1–T3).

Results

Nursery phase
The level of CP in the diet (Table 4) did not affect (P>0.05) ADG, ADFI, FGR, and FFLG of nursery pigs, but final body weight (BW) was higher (P<0.007) in pigs fed the standard CP diet (T0). The addition of lysine to LPD did not improve (P>0.05) growth performance compared to the control LPD (T1); but FFLG was increased in a quadratic pattern (P<0.05).

The level of CP in the diet (Table 5) did not affect (P>0.05) BF, LMA, and LMP. The addition of lysine to LPD had a quadratic effect on BF (P<0.01), LMA (P<0.001), and LMP (P<0.05). Supplementation of LPD with 1 g/kg more lysine (T2) resulted in the highest (P<0.05) LMP (51.2%) compared to the standard CP diet (49.08%).

The PUN concentration (Table 5) was 32.26% higher in pigs fed the standard CP diet (P<0.01). The addition of lysine to LPD did not decrease PUN concentration (P>0.05).

Growing phase
The ADG (Table 6) tended to be higher in pigs fed the standard CP diet (P<0.09), which tended to be heavier (P<0.09), and to have more fat free lean gain (P<0.01) compared to pigs fed LPD (T1). The addition of lysine to LPD quadratically increased ADG (P<0.01), ADFI (P<0.05), final BW (P<0.006), and FFLG (P<0.002); but the higher level of lysine supplementation (T3) did not increase BW which was similar (P>0.05) to that observed in pigs fed LPD with the standard lysine level (T1).

Backfat thickness (Table 7) was higher (P<0.05) and LMA was lower (P<0.038)

Table 4. Growth performance (s.d.) of nursery barrows fed a standard diet or a low-protein diet supplemented with lysine

T	CP (g/kg)	LYS (g/kg)	Growth performance[1]				
			ADG (kg/day)	ADFI (kg/day)	FGR (kg/kg)	BW (kg)	FFLG (kg/day)
0	205	10.1	0.64 (0.02)	1.04 (0.07)	1.67 (0.10)	26.43 (0.53)	0.25 (0.01)
1	174	10.1	0.59 (0.02)	0.97 (0.05)	1.63 (0.07)	23.99 (0.38)	0.23 (0.01)
2	174	11.1	0.60 (0.02)	1.02 (0.05)	1.68 (0.07)	24.58 (0.38)	0.24 (0.01)
3	174	12.1	0.59 (0.02)	0.99 (0.05)	1.69 (0.07)	24.44 (0.38)	0.23 (0.01)
P value of specific contrasts							
Standard vs. low-protein			0.23	0.46	0.83	0.007	0.17
Linear			0.81	0.70	0.51	0.35	0.92
Quadratic			0.30	0.30	0.61	0.12	0.05

[1]All variables were analysed using the GLM procedure of SAS (1999) with initial body weight (10.58±1.42 kg) as covariate.
T=treatment; CP=crude protein; LYS=lysine; ADG=average daily gain; ADFI=average daily feed intake; FGR=feed:gain ratio; BW=body weight; FFLG=fat free lean gain.

Table 5. Carcass characteristics and plasma urea nitrogen concentration (s.d.) of nursery barrows fed a standard diet or a low-protein diet supplemented with lysine

T	CP (g/kg)	LYS (g/kg)	Carcass characteristics[1]			PUN (mg/dL)
			BF (mm)	LMA (cm²)	LMP	
0	205	10.1	2.0 (0.09)	11.45 (0.41)	49.08 (0.52)	21.30 (2.18)
1	174	10.1	2.0 (0.06)	10.73 (0.30)	50.28 (0.38)	14.09 (1.57)
2	174	11.1	2.2 (0.06)	11.93 (0.30)	51.20 (0.38)	13.88 (1.57)
3	174	12.1	2.0 (0.06)	10.74 (0.30)	49.83 (0.38)	15.31 (1.57)
P value of specific contrasts						
Standard vs. low-protein			0.85	0.42	0.14	0.01
Linear			0.98	0.91	0.46	0.79
Quadratic			0.01	0.001	0.05	0.52

[1]All variables were analysed using the GLM procedure of SAS (1999) with initial body weight as covariate.
T=treatment; CP=crude protein; LYS=lysine; BF= backfat thickness; LMA=*Longissimus* muscle area; LMP=lean meat percentage; PUN=plasma urea nitrogen concentration.

Table 6. Growth performance (s.d.) of growing barrows fed a standard diet or a low-protein diet supplemented with lysine

T	CP (g/kg)	LYS (g/kg)	Growth performance[1]				
			ADG (kg/day)	ADFI (kg/day)	FGR (kg/kg)	BW (kg)	FFLG (kg)
0	165	8.3	0.85 (0.03)	1.80 (0.15)	2.13 (0.17)	56.45 (0.90)	0.338 (0.03)
1	140	8.3	0.79 (0.02)	1.71 (0.11)	2.16 (0.12)	52.92 (0.64)	0.300 (0.02)
2	140	9.3	0.85 (0.02)	1.88 (0.11)	2.21 (0.12)	55.18 (0.64)	0.330 (0.02)
3	140	10.3	0.79 (0.02)	1.58 (0.11)	1.99 (0.12)	52.85 (0.64)	0.298 (0.02)
P value of specific contrasts							
Standard vs. low-protein			0.09	0.84	0.67	0.09	0.01
Linear			0.85	0.40	0.29	0.83	0.90
Quadratic			0.01	0.05	0.32	0.006	0.002

[1]All variables were analysed using the GLM procedure of SAS (1999) with initial body weight (25.57±2.38 kg) as covariate.
T=treatment; CP=crude protein; LYS=lysine; ADG=average daily gain; ADFI=average daily feed intake; FGR=feed:gain ratio; BW=body weight; FFLG=fat free lean gain.

in pigs fed LPD (T1) compared to pigs fed the standard CP diet (T0). The addition of lysine to LPD had a quadratic effect on BF ($P<0.05$), LMA ($P<0.001$), and LMP ($P<0.05$). However, supplementation of LPD with 1 g/kg more lysine increased LMA to a similar level as in pigs fed standard CP diet ($P>0.05$).

The PUN concentration (Table 7) decreased ($P<0.02$) by 33.7% when the level of dietary CP was reduced from 165 to 140 g/kg. The addition of lysine to LPD did not decrease PUN concentration ($P>0.05$).

Finishing phase

The ADFI and FGR were higher ($P<0.03$) in pigs fed the standard CP diet compared to pigs fed LPD (T1) (Table 8). The addition of lysine to LPD had a quadratic effect on ADFI ($P<0.02$) and FGR ($P<0.009$). The lowest ($P<0.05$)

Table 7. Carcass characteristics and plasma urea nitrogen concentration (s.d.) of growing barrows fed a standard diet or a low-protein diet supplemented with lysine

T	CP (g/kg)	LYS (g/kg)	Carcass characteristics[1]			PUN (mg/dL)
			BF (mm)	LMA (cm^2)	LMP	
0	165	8.3	6.17 (0.07)	21.84 (0.76)	44.12 (1.66)	19.74 (1.55)
1	140	8.3	6.80 (0.05)	18.97 (0.54)	43.42 (1.18)	8.16 (1.10)
2	140	9.3	7.30 (0.05)	21.45 (0.54)	44.14 (1.18)	8.74 (1.10)
3	140	10.3	6.40 (0.05)	18.60 (0.54)	43.18 (1.18)	9.90 (1.10)
P value of specific contrasts						
Standard vs. low-protein			0.09	0.038	0.21	0.02
Linear			0.36	0.76	0.63	0.53
Quadratic			0.05	0.001	0.05	0.72

[1]All variables were analysed using the GLM procedure of SAS (1999) with initial body weight as covariate.
T=treatment; CP=crude protein; LYS=lysine; BF=backfat thickness; LMA=*Longissimus* muscle area; LMP=lean meat percentage; PUN=plasma urea nitrogen concentration.

ADFI and FGR were observed in pigs fed LPD with the standard lysine level (T1).

The reduction of CP in the diets (Table 9) did not affect carcass characteristics ($P>0.05$). The addition of lysine to LPD affected BF thickness linearly ($P<0.04$) and quadratically ($P<0.08$) and LMA quadratically ($P<0.08$). The lowest ($P<0.05$) BF thickness was observed in pigs fed LPD supplemented with 2 g/kg more lysine (T3).

Pigs fed reduced CP diet (118 g/kg) had 42.3% less PUN concentration (Table 9). The addition of lysine to LPD did not decrease PUN concentration ($P>0.05$).

Discussion

Growth performance

The CP concentrations in the sorghum-soybean meal, AA-supplemented, LPD were based on previous investigations conducted by our research team for nursery

Table 8. Growth performance (s.d.) of finishing barrows fed a standard diet or a low-protein diet supplemented with lysine

T	CP (g/kg)	LYS (g/kg)	Growth performance[1]				
			ADG (kg/day)	ADFI (kg/day)	FGR (kg/kg)	BW (kg)	FFLG (kg/day)
0	140	6.6	0.94 (0.06)	2.89 (0.13)	3.10 (0.10)	101.6 (1.98)	0.30 (0.02)
1	118	6.6	0.99 (0.04)	2.15 (0.09)	2.25 (0.07)	97.7 (1.40)	0.31 (0.02)
2	118	7.6	0.94 (0.04)	2.83 (0.09)	2.84 (0.07)	103.1 (1.40)	0.32 (0.02)
3	118	8.6	0.94 (0.04)	2.33 (0.09)	2.47 (0.07)	98.5 (1.40)	0.33 (0.02)
P value of specific contrasts							
Standard vs. low-protein			0.72	0.03	0.003	0.72	0.55
Linear			0.95	0.54	0.32	0.95	0.45
Quadratic			0.48	0.02	0.009	0.48	0.70

[1]All variables were analysed using the GLM procedure of SAS (1999) with initial body weight (54.11±3.77 kg) as covariate.
T=treatment; CP=crude protein; LYS=lysine; ADG=average daily gain; ADFI=average daily feed intake; FGR=feed:gain ratio; BW=body weight; FFLG=fat free lean gain.

Table 9. Carcass characteristics and plasma urea nitrogen concentration (s.d.) of finishing barrows fed standard diet or a low-protein diet supplemented with lysine

T	CP (g/kg)	LYS (g/kg)	Carcass characteristics[1]			PUN (mg/dL)
			BF (mm)	LMA (cm²)	LMP	
0	140	6.6	12.50 (0.79)	36.78 (1.38)	41.99 (0.35)	21.67
1	118	6.6	13.00 (0.56)	32.16 (0.97)	40.90 (0.25)	12.11
2	118	7.6	14.29 (0.56)	36.53 (0.97)	41.64 (0.25)	13.06
3	118	8.6	10.75 (0.56)	30.57 (0.97)	40.43 (0.25)	12.37
P value of specific contrasts						
Standard vs. low-protein			0.11	0.49	0.26	0.001
Linear			0.04	0.46	0.55	0.61
Quadratic			0.08	0.08	0.14	0.62

[1] All variables (except initial ones) were analysed using the GLM procedure of SAS (1999) with initial body weight as covariate.
T=treatment; CP=crude protein; LYS=lysine; BF=backfat thickness; LMA=*Longissimus* muscle area; LMP=lean meat percentage; PUN=plasma urea nitrogen concentration.

(Trujillo *et al*. 2007), growing (Martínez-Aispuro *et al*. 2009) and finishing (Figueroa *et al*. 2008) pigs. In the current research, the decrease in dietary CP for fattening pigs fed sorghum-soybean meal, AA-supplemented diets, did not adversely affect the growth performance of nursery and finishing pigs, but lowered ADG of growing pigs, compared with those fed diets with the recommended NRC (1998) level of CP. This is consistent with previous reports, which found that it is possible to obtain an acceptable performance when dietary CP is reduced by 6% in diets similar to those used in this investigation (Martínez-Aispuro *et al*. 2009; Reyes 2010; Trujillo *et al*. 2007), or wheat-corn-barley, supplemented with lysine, methionine, threonine, tryptophan, isoleucine and valine (Le Bellego and Noblet 2002), or corn-soybean meal supplemented with lysine, methionine, threonine, tryptophan, and valine (Mavromichalis *et al*. 1998). In other studies it was found that the reduction of CP in sorghum-soybean meal (Martínez-Aispuro *et al*. 2009; Rivera *et al*. 2010; Saldaña *et al*. 2009; Zamora *et al*. 2010) or corn-soybean meal diets (Figueroa *et al*. 2002, 2004; Gómez *et al*. 2002; Tuitoek *et al*. 1997; Zervas and Zijlstra 2002) decreased the growth performance of pigs. So, a lowering of up to 4% CP is recommended in LPD, because a higher reduction can lead to deficiencies of AA, thereby limiting the growth performance of pigs (Cervantes-Ramírez, Cromwell, and Stahly 1991; Gómez *et al*. 2002; Page, Southern, and Waltkins 1993; Ward and Southern 1995).

Supplementation with lysine increased growth performance, confirming other findings of our research team (López *et al*. 2010). That may imply that the lysine requirement is higher than the level suggested by NRC (1998) for fattening pigs. In other reports it was found that 10.3 g/kg of true digestible lysine was enough to sustain growth performance in pigs fed LPD (Chiaradia *et al*. 2009).

Carcass characteristics

Carcass characteristics were not affected by decreasing dietary CP, except for an increase in BF thickness in growing pigs. These results are in agreement with findings of other researchers (Figueroa *et al*. 2002, 2003, 2004; Gómez *et al*. 2002; Le Bellego *et al*. 2001; Martínez-Aispuro *et al*. 2009;

Zamora *et al*. 2010). Supplementation of LPD with lysine improved pig carcass variables, indicating a higher lysine requirement than that recommended by the NRC (1998) for fattening pigs, or that these pigs have a greater potential for lean tissue deposition. The increase in BF thickness could also suggest a greater imbalance between AA by adding lysine to LPD. This variability in results may be due to the level of lysine, the genetic capacity for lean tissue retention, and to the sex of the pigs used in this experiment (Hahn, Biehl, and Baker 1995; Hansen and Lewis 1993).

That the addition of 1 g/kg more lysine to LPD improved lean meat percentage in nursery and growing pigs, and LMA in growing pigs, may indicate a higher lysine requirement for these pigs than the levels recommended by the NRC (1998), which agrees with reports of other researchers for growing pigs (Hansen and Lewis 1993; López *et al*. 2010; Medina 2002; Witte *et al*. 2000). However, the highest level of lysine addition (2 g/kg; T3) had no effect on pigs, and one reason may be that the levels of threonine, methionine and tryptophan were the same in all diets, producing an imbalance in this treatment.

Plasma urea nitrogen concentration

The decrease in PUN concentration as dietary CP was decreased is similar to that found in pigs fed diminished CP in sorghum-soybean meal (Martínez-Aispuro *et al*. 2009; Reyes 2010; Rivera *et al*. 2010; Trujillo *et al*. 2007; Zamora *et al*. 2010) or corn-soybean meal (Figueroa *et al*. 2002; Le Bellego and Noblet 2002) LPD diets, in which there was a linear reduction in PUN. This indicates a better nitrogen utilization of pigs fed LPD (Coma, Carrion, and Zimmerman 1995). For every percentage unit of decrease in dietary CP, there was between 8.5% and 12.5% reduction in nitrogen excretion, thereby also lowering the odor and emission of NH_3 produced by the excess of nitrogen ingested by pigs fed standard diets (Kerr, McKeith, and Easter 1995).

Conclusions

Pigs fed LPD during the nursery and growing phases had similar growth performance and carcass characteristics as pigs fed standard CP diets. However, in the finishing phase, the decrease in CP concentration reduced some growth performance variables and increased carcass fatness of pigs.

Crystalline lysine supplementation helped to improve growth performance and carcass characteristics of fattening pigs fed low-protein diets.

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