Effects of increasing L-lysine HCl in corn- or sorghum-soybean meal-based diets on growth performance and carcass characteristics of growing-finishing pigs[1,2]

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ABSTRACT: We conducted three experiments to determine the effects of increasing L-lysine HCl in growing-finishing pig diets. Experiments 1 and 2, conducted at the Kansas State University research center, each used 360 growing-finishing pigs with initial BW of 56 and 63 kg, respectively. Dietary treatments were sorghum- (Exp. 1) or corn- (Exp. 2) soybean meal-based and consisted of a control (no L-lysine HCl) or 0.15, 0.225, and 0.30% L-lysine HCl replacing lysine provided by soybean meal. Experiment 3 was conducted in a commercial research facility using a total of 1,200 gilts with an initial BW of 29 kg. Pigs were allotted to one of eight dietary treatments fed in four phases. These consisted of a positive control diet with no added L-lysine HCl and the control diet with 0.05, 0.10, 0.15, 0.20, 0.25, and 0.30% L-lysine HCl replacing the lysine provided by soybean meal. The eighth dietary treatment was a negative control diet with no added L-lysine HCl and formulated to contain 0.10% less total lysine than the other treatments to ensure that dietary lysine was not above required levels. In Exp. 1, increasing L-lysine HCl decreased (linear, $P < 0.01$) ADG, feed efficiency (G:F), and percentage lean and increased (linear, $P < 0.01$) backfat depth. In Exp. 2, increasing L-lysine HCl decreased (quadratic, $P < 0.03$) ADG, G:F, and ADFI, but carcass characteristics were not affected. In Exp. 3, increasing L-lysine HCl decreased ADG (linear, $P < 0.01$) and G:F (quadratic $P < 0.03$). In all three experiments, the greatest negative responses were observed when more than 0.15% L-lysine HCl was added to the diet. Therefore, unless other synthetic amino acids are added to the diet, no more than 0.15% L-lysine HCl should replace lysine from soybean meal in a corn- or sorghum-soybean meal-based diet to avoid deficiencies of other amino acids. Based on the content of diets containing 0.15% Lysine-HCl, it appears the requirements for methionine plus cystine expressed as ratios relative to lysine are not greater than 50% during the early growing-finishing period (30 to 45 kg) and 62% during the late finishing period (90 to 120 kg) on a true digestible basis. For similar periods, the ratio requirements for threonine are not greater than 59% and 64% on a true digestible basis.

Key Words: Growth, Lysine, Pigs

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Introduction

The use of crystalline lysine (L-lysine HCl) to replace a portion of the lysine provided by soybean meal in diets for growing-finishing pigs is a common practice among swine producers. Research has indicated that the decrease in growth performance observed in growing-finishing pigs by reducing the crude protein content of the diet by 2% can be alleviated with the dietary addition of approximately 0.15% L-lysine HCl (Baker et al., 1975; Easter and Baker, 1980). In addition to the frequent economic advantage, the reduction in crude protein content when adding crystalline amino acids to the diet has been proven to be an effective strategy for lowering nitrogen excretion in swine waste (Pierce et al., 1994; Carter et al., 1996). Because the amount of soybean meal is decreased with the addition of L-lysine HCl, the concentrations of other amino acids in the diet also are decreased. Therefore, the amount of L-lysine HCl that can be added to the diet should be based on the second limiting amino acid.

Historically, the maximum addition of L-lysine HCl to reduced-protein diets of growing-finishing pigs has

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been 0.15%; further addition of Lysine HCl and removal of soybean meal was thought to cause an essential amino acid deficiency. Recent reviews (Baker, 1997; NRC, 1998) have suggested that concentrations of essential amino acids relative to lysine should be higher than thought previously (NRC, 1988). If requirement estimates for other amino acids relative to lysine are indeed increased as these reviews suggest, then the traditional addition of 0.15% L-lysine HCl and removal of soybean meal in corn or sorghum based diets for growing-finishing pigs would reduce performance. Therefore, the objective of this experiment was to determine the quantity of L-lysine HCl that can be added to corn- or sorghum-soybean meal-based diets for growing-finishing pigs without adversely affecting growth performance and carcass traits.

Procedures

Experiments 1 and 2. One hundred and sixty PIC (L326 × C22) finishing pigs were used in each experiment; initial BW was 56 and 63 kg for Exp. 1 and 2, respectively. Pigs were housed at the Kansas State University Swine Teaching and Research Center in a modified open-front building with supplemental mechanical ventilation and 50% slatted floor pens. Ten pigs were housed per pen with dimensions of 1.8 × 4.9 m. Pens were equipped with a two-hole dry feeder and a single nipple waterer. Pigs were allowed ad libitum access to feed and water. Experiment 1 was conducted from October to December, and Exp. 2 from January to March. Similar procedures were used in both experiments with the exception that sorghum-soybean meal-based diets (Table 1) were used in Exp. 1, and corn-soybean meal-based diets were used in Exp. 2. Pigs in Exp. 1 and 2 were allotted randomly on the basis of initial BW and gender to one of the four dietary treatments in a randomized complete block design with 10 pigs per pen and four replicate pens per treatment (two gilt and two barrow replicates).

Dietary Treatments. The grains used in these experiments were U.S. No. 2 quality obtained from a local source. The sorghum was a low tannin variety grown in northeast Kansas. Dietary treatments were fed in growing (56 to 80 kg and 63 to 80 kg) and finishing (80 to 114 kg and 80 to 109 kg for Exp. 1 and 2, respectively) phases with diets formulated to contain 0.70 and 0.55% total lysine, respectively. The lysine levels used were estimated to be at or slightly below the nutrient requirement of pigs with this lean growth potential (325 g/d) and for these weight ranges (50 to 80 kg and 80 to 120 kg) (NRC, 1998) to prevent overestimating the amount of L-lysine HCl that could be added. Dietary treatments included a control diet (no added L-lysine HCl) or a control diet with 0.15, 0.225, and 0.30% L-lysine HCl replacing the lysine provided by soybean meal. Dietary crude protein in feed samples was determined by AOAC (1984) procedures, and values agreed closely with calculated levels (Tables 1 and 2).

Response Criteria. All pigs and feeders were weighed every 14 d to calculate ADG, ADFI, and gain:feed ratio (**G:F**). When the mean weight of pigs within a block reached 80 kg, all pigs were switched from growing to finishing diets. At the termination of the study, pigs were sent to USDA-inspected packing plant (Farmland Foods, Crete, NE) for carcass data collection from each individual pig. Yield was calculated as hot carcass weight divided by body weight. Fat depth and loin depth were measured with an optical probe inserted between the third and fourth from the last rib (counting from the ham end of the carcass) and 7 cm off of the midline of the hot carcass with the skin removed. Fat-free lean index was calculated according to NPPC (1994) procedures.

Experiment 3. A total of 1,200 gilts (PIC C22 × 337) with an initial weight of 29 kg were housed in a commercial research finishing facility located in southwestern Minnesota. The finishing facility was a doubled curtain-sided, deep pit barn that operates on natural ventilation during the summer and on mechanically assisted ventilation during the winter and had 48 totally slatted concrete pens. Each pen was equipped with a 4-hole dry self-feeder and one-cup waterer. Pigs were allotted to one of eight dietary treatments in a randomized complete block design with 25 pigs/pen and six pens/treatment. Pen dimensions were 3.05 m × 5.49 m. The experiment was conducted from August to December.

Dietary Treatments. The experimental treatments were corn-soybean meal-based diets fed in four phases (Tables 3, 4, 5, and 6) and consisted of a positive control diet with no added L-lysine HCl or the control diet with 0.05, 0.10, 0.15, 0.20, 0.25, and 0.30% L-lysine HCl replacing the lysine provided by soybean meal. A negative control treatment with no added L-lysine HCl was formulated to contain 0.10% less total lysine than the other treatments to ensure that dietary lysine was not above required levels. Data from a previous study evaluating increasing lysine:calorie ratios (De la Llata et al., 2000) were used to determine the appropriate lysine level for this genotype in these facilities. The dietary treatments were formulated using nutrient values from NRC (1998) for all ingredients. Vitamins and trace minerals met or exceeded NRC (1998) recommendations. Dietary crude protein and amino acids in feed samples were analyzed according to the AOAC (1984) methods at the Experiment Station Chemical Laboratories at the University of Missouri. Amino acid analysis (Tables 7 and 8) was performed by ion exchange chromatography following acid hydrolysis. Methionine and cystine were determined following oxidation with performic acid. Tryptophan was determined following alkaline hydrolysis.

Response Criteria. Pig weights and feed disappearance were measured on a pen basis every 14 d to calculate ADG, ADFI, and G:F. Diet phase changes occurred approximately every 28 d. Diets were formulated for a target pig weight range of 30 to 45, 45 to 70, 70 to 90, and 90 to 120 kg for phases 1 to 4, respectively. Actual

Table 1. Diet composition for Exp. 1 (as-fed basis)

	56 to 80 kg					80 to 120 kg				
	L-lysine HCl, %					L-lysine HCl, %				
Ingredient, %	0	0.15	0.225	0.30		0	0.15	0.225	0.30	
Sorghum	80.62	84.62	86.70	88.79		85.84	89.95	91.85	93.95	
Soybean meal, 46.5%	17.10	12.90	10.70	8.50		11.80	7.50	5.50	3.30	
Monocalcium phosphate	0.78	0.85	0.90	0.93		0.88	0.95	0.98	1.00	
Limestone	0.90	0.88	0.88	0.88		0.88	0.85	0.85	0.85	
Salt	0.35	0.35	0.35	0.35		0.35	0.35	0.35	0.35	
Vitamin premix[a]	0.15	0.15	0.15	0.15		0.15	0.15	0.15	0.15	
Trace mineral premix[b]	0.10	0.10	0.10	0.10		0.10	0.10	0.10	0.10	
Lysine HCl	—	0.15	0.225	0.30		—	0.15	0.225	0.30	
Calculated analysis[c]										
Lysine, %	0.70	0.70	0.70	0.70		0.55	0.55	0.55	0.55	
CP, %	14.4	12.8	12.0	11.2		12.4	10.7	9.9	9.1	
CP, % analyzed	14.3	12.4	12.8	11.4		13.2	11.4	10.4	10.0	
ME, Mcal/kg	3.27	3.26	3.26	3.25		3.26	3.26	3.26	3.25	
Total	Ratio relative to lysine (%)[d]				*NRC*[e]	Ratio relative to lysine (%)[d]				*NRC*[f]
Methionine	36	33	32	30	27	41	37	35	33	27
Met + Cys	74	67	64	61	59	84	75	71	67	58
Threonine	81	72	**67**	**63**	68	88	77	71	**65**	68
Tryptophan	28	24	23	21	19	30	25	23	21	18
Isoleucine	96	85	80	74	56	105	91	84	77	55
Apparent digestible										
Methionine	38	34	32	30	28	44	38	36	33	28
Met + Cys	71	62	**58**	**54**	59	81	69	64	**58**	62
Threonine	76	64	**59**	**54**	61	83	68	**61**	**55**	64
Tryptophan	27	23	21	19	16	30	25	22	20	17
Isoleucine	100	86	79	72	56	111	92	84	75	55
True digestible										
Methionine	41	36	34	32	27	48	42	39	36	27
Met + Cys	76	67	62	**58**	59	87	75	69	63	60
Threonine	88	76	70	**64**	65	98	81	74	66	65
Tryptophan	30	26	24	21	18	33	27	24	22	19
Isoleucine	107	92	85	78	56	119	100	90	81	56

[a]Provided the following per kilogram of complete diet: vitamin A, 8,818 IU; vitamin D, 1,323 IU; vitamin E, 35.3 IU; menadione (menadione sodium bisulfate complex), 3.5 mg; vitamin B_{12}, 0.04 mg; riboflavin, 7.9 mg; pantothenic acid, 26.5 mg; and niacin, 44.1.
[b]Provided the following per kilogram of complete diet: Mn, 40 mg; Fe, 165 mg; Zn, 165 mg; Cu, 17 mg; I, 0.3 mg; and Se, 0.3 mg.
[c]Calculated values for ingredients from NRC (1998) were used in diet formulation.
[d]Numbers in bold are calculated to be deficient compared to estimates of NRC (1998).
[e]NRC (1998) amino acid requirements for pigs from 50 to 80 kg with 325 g/d of lean accretion.
[f]NRC (1998) amino acid requirements for pigs from 80 to 120 kg with 325 g/d of lean accretion.

pig weight ranges were 29 to 51, 51 to 74, 74 to 96, and 96 to 120 kg.

Statistical Analysis. Analysis of variance was used to analyze the data from each experiment as randomized complete block designs using the GLM procedures of SAS (SAS Inst. Inc., Cary, NC). Linear and quadratic polynomial contrasts (Peterson, 1985) were used to determine the effects of increasing L-lysine HCl. In Exp. 1 and 2 linear and quadratic coefficients were adjusted using the IML procedure of SAS to obtain appropriate coefficients for unequally spaced treatments. A single comparison contrast was used in Exp. 3 to compare differences between the negative and positive controls (no added L-lysine HCl). Final weight was used as a covariate to analyze the carcass characteristics in Exp. 1 and 2. Pen was used as the experimental unit for all response criteria.

Results

Experiment 1. During phase 1 (56 to 80 kg), increasing L-lysine HCl tended to decrease ADG (linear, $P < 0.06$) and G:F (linear $P < 0.01$; Table 9). Average daily feed intake increased and then decreased (quadratic, $P < 0.05$) with increasing L-lysine HCl. In phase 2 (80 to 114 kg), ADG and G:F decreased (linear, $P < 0.01$) with increasing L-lysine HCl but average daily feed intake was not affected. For the overall experiment, increasing L-lysine HCl decreased (linear, $P < 0.01$) ADG and G:F and ADFI was unchanged. This resulted in pigs fed increasing L-lysine HCl having lower final BW (linear, $P < 0.01$; Figure 1). Increasing L-lysine HCl increased and then decreased (quadratic, $P < 0.06$) carcass yield. Backfat depth increased (linear $P < 0.01$) and percentage lean and fat-free lean index decreased (linear, *P*

Table 2. Diet composition for Exp. 2 (as-fed basis)

	63 to 80 kg					80 to 120 kg				
	L-lysine HCl, %					L-lysine HCl, %				
Ingredient, %	0	0.15	0.225	0.30		0	0.15	0.225	0.30	
Corn	81.22	85.22	87.30	89.28		86.54	90.52	92.63	94.64	
Soybean meal, 46.5% CP	16.50	12.30	10.10	8.00		11.10	6.90	4.70	2.60	
Monocalcium phosphate (21% P)	0.79	0.85	0.90	0.93		0.88	0.95	1.00	1.00	
Limestone	0.89	0.88	0.88	0.89		0.88	0.88	0.85	0.86	
Salt	0.35	0.35	0.35	0.35		0.35	0.35	0.35	0.35	
Vitamin premix[a]	0.15	0.15	0.15	0.15		0.15	0.15	0.15	0.15	
Trace mineral premix[b]	0.10	0.10	0.10	0.10		0.10	0.10	0.10	0.10	
Lysine HCl	—	0.15	0.225	0.30		—	0.15	0.225	0.30	
Calculated analysis[c]										
Lysine, %	0.70	0.70	0.70	0.70		0.55	0.55	0.55	0.55	
CP, %	14.4	12.8	12.0	11.2		12.4	10.7	9.9	9.1	
CP, % analyzed	15.3	14.1	12.1	11.4		13.7	11.0	10.2	9.9	
ME, Mcal/kg	3.32	3.32	3.33	3.33		3.32	3.32	3.33	3.33	
Total	Ratio relative to lysine (%)[d]				*NRC*[e]	Ratio relative to lysine (%)[d]				*NRC*[f]
Methionine	35	32	31	29	27	40	36	34	32	27
Met + Cys	74	68	65	62	59	84	76	72	68	58
Threonine	76	**67**	**62**	**57**	68	82	70	**64**	**58**	68
Tryptophan	22	**18**	**17**	**15**	19	22	18	**15**	**13**	18
Isoleucine	77	65	59	**53**	56	78	63	56	**48**	55
Apparent digestible										
Methionine	38	34	32	30	28	44	39	36	33	28
Met + Cys	70	61	**57**	**53**	59	79	68	62	**57**	62
Threonine	71	**60**	**55**	**49**	61	77	**63**	**56**	**49**	64
Tryptophan	21	17	**15**	**13**	16	21	**16**	**13**	**11**	17
Isoleucine	79	65	58	**51**	56	83	64	55	**47**	55
True digestible										
Methionine	37	33	31	29	27	42	37	35	33	27
Met + Cys	68	60	**57**	**53**	59	77	66	61	**56**	60
Threonine	75	**64**	**59**	**54**	65	81	67	**60**	**54**	65
Tryptophan	22	18	**16**	**14**	18	23	**18**	**15**	**12**	19
Isoleucine	78	65	59	**52**	56	81	64	56	**48**	56

[a]Provided the following per kilogram of complete diet: vitamin A, 8,818 IU; vitamin D, 1,323 IU; vitamin E, 35.3 IU; menadione (menadione sodium bisulfate complex), 3.5 mg; vitamin B_{12}, 0.04 mg; riboflavin, 7.9 mg; pantothenic acid, 26.5 mg; and niacin, 44.1.

[b]Provided the following per kilogram of complete diet: Mn, 40 mg; Fe, 165 mg; Zn, 165 mg; Cu, 17 mg; I, 0.3 mg; and Se, 0.3 mg.

[c]Calculated values for ingredients from NRC (1998) were used in diet formulation.

[d]Numbers in bold are calculated to be deficient compared to estimates of NRC (1998).

[e]NRC (1998) amino acid requirements for pigs from 50 to 80 kg with 325 g/d of lean accretion.

[f]NRC (1998) amino acid requirements for pigs from 80 to 120 kg with 325 g/d of lean accretion.

< 0.01) with increasing L-lysine HCl. Loin depth was not affected.

Experiment 2. In phase 1 (63 to 80 kg), increasing L-lysine HCl decreased ADG and G:F (quadratic $P < 0.02$; Table 10), and the greatest negative response was observed in pigs fed more than 0.15% L-lysine. Average daily feed intake tended to increase and then decrease (quadratic, $P < 0.08$) with increasing L-lysine HCl in the diet. During phase 2 (80 to 109 kg), increasing L-lysine HCl decreased ADG (quadratic, $P < 0.05$), ADFI (quadratic, $P < 0.01$), and G:F (linear, $P < 0.01$). For the overall experiment (63 to 109 kg), increasing L-lysine HCl decreased (quadratic, $P < 0.03$) ADG, ADFI, G:F, and final BW with the greatest negative response observed in pigs fed more than 0.15% L-lysine HCl (Figure 2). Increasing L-lysine HCl did not affect any of the carcass characteristics.

Experiment 3. During phase 1 (30 to 45 kg), increasing L-lysine HCl decreased (linear, $P < 0.02$) ADG and G:F (Table 11). The pigs fed the negative control tended to have lower ADG and G:F ($P < 0.10$) compared to pigs fed the diet without added L-lysine HCl. During phase 2 (45 to 70 kg), increasing L-lysine HCl decreased (quadratic, $P < 0.05$) ADG and G:F, and the largest decrease was observed for pigs fed more than 0.15% L-lysine HCl. Average daily gain tended ($P < 0.06$) and G:F was lower ($P < 0.02$) for pigs fed the negative control compared to those fed diet without added L-lysine HCl. In phase 3 (70 to 90 kg), increasing L-lysine HCl decreased ADG (linear, $P < 0.01$) and G:F (quadratic, $P < 0.02$). Average daily gain was lower ($P < 0.04$) and G:F tended to be lower ($P < 0.10$) for pigs fed the negative control compared to those fed diet without added L-lysine HCl. During phase 4 (90 to 120 kg), ADG tended to decrease (linear, $P < 0.06$) by increasing L-lysine HCl. For the overall experiment, increasing L-lysine HCl decreased ADG (linear, $P < 0.01$), G:F (quadratic, $P < 0.03$), and final BW (linear, $P < 0.01$; Figure 3). Compared to pigs

Table 3. Diet composition for pigs from 30 to 45 kg (Exp. 3 as-fed basis)

Ingredient, %	Negative control	L-lysine HCl, %							
		0	0.05	0.10	0.15	0.20	0.25	0.30	
Corn	58.55	54.84	56.22	57.61	59.00	60.49	61.85	63.23	
Soybean meal, 46.5% CP	32.55	36.31	34.88	33.44	32.00	30.46	29.02	27.59	
Choice white grease	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	
Monocalcium phosphate	1.33	1.30	1.30	1.30	1.30	1.30	1.33	1.33	
Limestone	1.00	0.98	0.98	0.98	0.98	0.98	0.98	0.98	
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	
Vitamin premix[a]	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	
Trace mineral premix[b]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	
L-lysine HCl	—	—	0.05	0.10	0.15	0.20	0.25	0.30	
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
Calculated analysis[c]									
Lysine, %	1.15	1.25	1.25	1.25	1.25	1.25	1.25	1.25	
CP, %	20.1	21.5	21	20.4	19.9	19.3	18.8	18.1	
ME, Mcal/kg	3.58	3.58	3.58	3.58	3.57	3.57	3.57	3.57	
Total	Calculated amino acid ratios (%) relative to lysine[d]								*NRC*[e]
Methionine	28	27	26	26	**25**	**25**	**24**	**23**	26
Met + Cys	58	57	**55**	**54**	**53**	**52**	**51**	**49**	57
Threonine	67	66	65	**63**	**61**	**59**	**57**	**56**	64
Tryptophan	21	21	21	20	19	19	**18**	**17**	18
Isoleucine	73	73	70	68	66	64	62	59	54
Apparent digestible									
Methionine	29	28	27	27	**26**	**25**	**25**	**24**	27
Met + Cys	**55**	**54**	**52**	**51**	**49**	**48**	**46**	**45**	57
Threonine	63	62	60	**58**	**56**	**54**	**52**	**50**	60
Tryptophan	21	21	20	19	18	18	**17**	**16**	17
Isoleucine	74	74	71	69	66	64	61	58	54
True digestible									
Methionine	29	28	27	26	26	**25**	**24**	**24**	26
Met + Cys	**56**	**54**	**53**	**51**	**50**	**48**	**47**	**46**	57
Threonine	66	65	63	**61**	**59**	**57**	**55**	**53**	63
Tryptophan	22	22	21	20	20	19	18	**17**	18
Isoleucine	74	74	71	69	66	64	61	59	54

[a]Provided the following per kilogram of complete diet: vitamin A, 8,818 IU; vitamin D, 1,323 IU; vitamin E, 35.3 IU; menadione (menadione sodium bisulfate complex), 3.5 mg; vitamin B_{12}, 0.04 mg; riboflavin, 7.9 mg; pantothenic acid, 26.5 mg; and niacin, 44.1.

[b]Provided the following per kilogram of complete diet: Mn, 40 mg; Fe, 165 mg; Zn, 165 mg; Cu, 17 mg; I, 0.3 mg; and Se, 0.3 mg.

[c]Calculated values from NRC (1998) were used in diet formulation.

[d]Numbers in bold are calculated to be deficient compared to estimates of NRC (1998).

[e]NRC (1998) amino acid requirements for pigs from 20 to 50 kg.

fed the diets without added L-lysine HCl, those fed the negative control diet had lower ($P < 0.01$) ADG, G:F, and final BW for the overall period.

Discussion

Sorghum diet—Experiment 1. Increasing L-lysine HCl in sorghum-based diets decreased ADG and G:F with the greatest negative response observed in pigs fed more than 0.15% L-lysine HCl. These results agree with those found by Hansen et al. (1993), who observed a decrease in growth performance for pigs fed a 12% crude protein sorghum-soybean meal-based diet with 0.26% L-lysine HCl added when compared to those fed a 16% intact CP diet. Similar results were obtained by Ward and Southern (1995), who reported that increasing L-lysine HCl from 0.12 to 0.69% decreased ADG and G:F.

In our study, we observed that no more than 0.15% L-lysine HCl should be used to replace the lysine in soybean meal in order to maintain growth performance. However, according to the NRC (1998), only one of the dietary treatments was deficient in amino acids on a true digestible basis, i.e., the 0.30% L-lysine HCl diet from 56 to 80 kg (Table 1). According to Cohen and Tanskley (1976), threonine is the second limiting amino acid after lysine in sorghum for growing-finishing pigs. On an apparent digestible basis, threonine was calculated to be deficient on the 0.225 and 0.30% L-lysine HCl treatments for both phases. In addition, methionine + cystine were calculated to be deficient for the 0.225 and 0.30% L-lysine HCl treatments from 56 to 80 kg and for the 0.30% L-lysine HCl treatment from 80 to 120 kg. On a total basis, threonine was calculated to be deficient for the 0.225 and 0.30% L-lysine HCl treatments from 56 to 80 kg and for the 0.30% L-lysine HCl treatment from 80 to 120 kg. Therefore, differences exist in the predicted quantity of L-lysine HCl that can be added to a sorghum-soybean meal-based diet for growing-finishing pigs, before other amino acids are deficient; the differences also depend on whether diets

Table 4. Diet composition for pigs from 45 to 70 kg (Exp. 3 as-fed basis)

Ingredient, %	Negative control	L-lysine HCl, % 0	0.05	0.10	0.15	0.20	0.25	0.30	
Corn	66.57	62.64	64.00	65.39	66.77	68.13	69.48	70.87	
Soybean meal, 46.5% CP	24.68	28.66	27.23	25.79	24.36	22.92	21.49	20.05	
Choice white grease	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	
Monocalcium phosphate	1.23	1.20	1.20	1.20	1.20	1.20	1.23	1.23	
Limestone	0.95	0.93	0.95	0.95	0.95	0.98	0.98	0.98	
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	
Vitamin premix[a]	0.075	0.075	0.075	0.075	0.075	0.075	0.075	0.075	
Trace mineral premix[b]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	
L-lysine HCl	—	—	0.05	0.10	0.15	0.20	0.25	0.30	
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
Calculated analysis[c]									
Lysine, %	0.94	1.04	1.04	1.04	1.04	1.04	1.04	1.04	
CP, %	17.1	18.7	18.1	17.6	17.0	16.4	15.9	15.3	
ME, Mcal/kg	3.59	3.59	3.58	3.58	3.58	3.58	3.57	3.57	
Total	Calculated amino acid ratios (%) relative to lysine[d]								*NRC*[e]
Methionine	30	29	28	27	27	**26**	**25**	**24**	27
Met + Cys	63	60	59	**57**	**56**	**54**	**53**	**52**	59
Threonine	69	68	**66**	**64**	**62**	**60**	**57**	**55**	68
Tryptophan	21	21	21	20	19	**18**	**17**	**17**	19
Isoleucine	73	73	70	68	65	62	60	57	56
Apparent digestible									
Methionine	32	30	30	29	28	**27**	**26**	**25**	28
Met + Cys	60	**57**	**56**	**54**	**52**	**50**	**48**	**46**	59
Threonine	65	64	61	**59**	**57**	**54**	**52**	**49**	61
Tryptophan	21	21	20	19	18	17	**16**	**15**	16
Isoleucine	76	75	72	69	66	63	60	**56**	56
True digestible									
Methionine	31	30	29	28	27	27	**26**	**25**	27
Met + Cys	60	**57**	**56**	**54**	**52**	**50**	**49**	**47**	59
Threonine	69	67	65	**63**	**60**	**58**	**55**	**53**	65
Tryptophan	22	22	21	20	19	18	**17**	**17**	18
Isoleucine	75	75	72	69	66	63	60	57	56

[a]Provided the following per kilogram of complete diet: vitamin A, 8,818 IU; vitamin D, 1,323 IU; vitamin E, 35.3 IU; menadione (menadione sodium bisulfate complex), 3.5 mg; vitamin B_{12}, 0.04 mg; riboflavin, 7.9 mg; pantothenic acid, 26.5 mg; and niacin, 44.1.
[b]Provided the following per kilogram of complete diet: Mn, 40 mg; Fe, 165 mg; Zn, 165 mg; Cu, 17 mg; I, 0.3 mg; and Se, 0.3 mg.
[c]Calculated values from NRC (1998) were used in diet formulation.
[d]Numbers in bold are calculated to be deficient compared to estimates of NRC (1998).
[e]NRC (1998) amino acid requirements for gilts from 50 to 80 kg with 325 g/d of lean accretion.

are formulated on a total, apparent, or true digestible basis. The results from our experiment support the requirement estimates from the NRC (1998) on a total or apparent digestible basis but not on a true digestible basis. The reason for this lack of agreement may be the limited number of experiments used to determine true digestibility coefficients for amino acids in sorghum.

Adding 0.15, 0.225, or 0.30% L-lysine HCl to sorghum-based diets resulted in increased backfat depth and decreased lean percentage. These responses to addition of 0.15% L-lysine HCl to the diet were unexpected based on the growth data. Although no carcass parameters were evaluated in the study by Hansen et al. (1993), a 2% reduction in CP (from 15.4 to 13.3%) of the diet with the addition of 0.11% L-lysine HCl resulted in decreased growth performance. Their results support the differences observed in carcass parameters between the 0 and the 0.15% L-lysine HCl treatments (2% decrease in CP in both phases) in our study. Thus, for carcass characteristics, an amino acid other than lysine may be limiting when the CP content is decreased by more than 2% in L-lysine HCl supplemented sorghum-soybean meal diets for growing-finishing pigs. Another possibility for the increased fat depth is that a nutrient other than an amino acid is not supplied at a high enough quantity when 0.15% L-lysine HCl replaces 2% CP in a sorghum-soybean meal-based diet.

Supplementing low-protein (4% CP decrease) sorghum-soybean meal diets with crystalline amino acids has not resulted in maximum pig performance compared to sorghum-soybean meal diets formulated with intact protein sources (soybean meal) as the only source of amino acids (Philippe et al., 1992; Hansen et al., 1993; Ward and Southern, 1995). Research with corn-based amino acid-fortified diets has been more successful. Several studies have demonstrated that CP can be reduced by 4% units in corn-soybean meal-based diets with the addition of crystalline lysine, threonine, and tryptophan without affecting performance (Cromwell et al., 1983; Russell et al., 1983; Russell et al., 1986).

Table 5. Diet composition for pigs from 70 to 90 kg (Exp. 3 as-fed basis)

Ingredient, %	Negative control	L-lysine HCl, % 0	0.05	0.10	0.15	0.20	0.25	0.30	
Corn	74.98	71.18	72.57	73.95	75.32	76.67	78.06	79.41	
Soybean meal, 46.5% CP	16.45	20.28	18.84	17.41	15.97	14.54	13.10	11.67	
Choice white grease	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	
Monocalcium phosphate	1.13	1.10	1.10	1.10	1.10	1.13	1.13	1.13	
Limestone	0.93	0.93	0.93	0.93	0.95	0.95	0.95	0.98	
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	
Vitamin premix[a]	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	
Trace mineral premix[b]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	
L-lysine HCl	—	—	0.05	0.10	0.15	0.20	0.25	0.30	
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
Calculated analysis[c]									
Lysine, %	0.71	0.81	0.81	0.81	0.81	0.81	0.81	0.81	
CP, %	14.0	15.5	14.9	14.4	13.8	13.3	12.7	12.1	
ME, Mcal/kg	3.60	3.60	3.60	3.60	3.59	3.59	3.59	3.58	
Total	Calculated amino acid ratios (%) relative to lysine[d]								*NRC*[e]
Methionine	33	32	31	30	29	28	27	**26**	27
Met + Cys	71	67	65	63	61	59	**57**	**55**	59
Threonine	73	71	69	**66**	**63**	**60**	**58**	**55**	68
Tryptophan	21	21	20	19	**18**	**17**	**16**	**15**	19
Isoleucine	74	74	70	67	64	60	57	**53**	56
Apparent digestible									
Methionine	37	34	33	32	31	30	28	**27**	28
Met + Cys	68	64	61	59	**56**	**54**	**51**	**49**	59
Threonine	70	68	64	61	**58**	**55**	**52**	**49**	61
Tryptophan	21	21	20	18	17	**16**	**15**	**14**	16
Isoleucine	79	77	73	69	65	61	57	**53**	56
True digestible									
Methionine	36	33	32	31	30	29	28	27	27
Met + Cys	67	63	61	**58**	**56**	**54**	**52**	**49**	59
Threonine	74	71	68	65	**62**	**59**	**56**	**53**	65
Tryptophan	22	22	21	20	19	**17**	**16**	**15**	18
Isoleucine	78	77	73	69	65	61	57	**54**	56

[a]Provided the following per kilogram of complete diet: vitamin A, 6,614 IU; vitamin D, 992 IU; vitamin E, 26.5 IU; menadione (menadione sodium bisulfate complex), 2.6 mg; vitamin B_{12}, 0.03 mg; riboflavin, 6.0 mg; pantothenic acid, 19.8 mg; and niacin, 33.1.

[b]Provided the following per kilogram of complete diet: Mn, 27 mg; Fe, 110 mg; Zn, 110 mg; Cu, 11 mg; I, 0.2 mg; and Se, 0.2 mg.

[c]Calculated values from NRC (1998) were used in diet formulation.

[d]Numbers in bold are calculated to be deficient compared to estimates of NRC (1998).

[e]NRC (1998) amino acid requirements for gilts from 50 to 80 kg with 325 g/d of lean accretion.

The reason for the difference between corn- and sorghum-soybean meal-based diets in their effects on performance when crystalline amino acids are added is not known. Addition of dispensable nitrogen to low-protein, amino acid-supplemented, sorghum-soybean meal diets (Ward and Southern, 1995) or formulation of the diets on electrolyte balance (Hansen et al., 1993) has not been able to restore performance. High concentrations of tannins in diets containing sorghum grain have been shown to decrease nitrogen and amino acid digestibility (Cousins et al., 1981), but that was not a factor in the present experiment.

Corn Diets—Experiments 2 and 3. In Exp. 2, increasing L-lysine HCl in corn-based diets to more than 0.15% decreased ADG and G:F. This confirmed the results obtained with sorghum-based diets, that no more than 0.15% L-lysine HCl should be added to the diet of growing-finishing pigs without supplementation of other amino acids. We then conducted a large-scale study (Exp. 3) with pigs housed under commercial conditions to better titrate the pig's response to increasing levels of L-lysine HCl. The data from Exp. 3 also demonstrated that adding more than 0.15% L-lysine HCl decreased ADG and G:F. The results from both experiments agree with the traditional recommendation that CP can be decreased by 2% in corn-based diets when crystalline lysine is supplemented (Katz et al., 1973; Baker et al., 1975; Easter and Baker, 1980). In our studies, CP was decreased approximately 1.8% without affecting growth performance, whereas a decrease in CP of approximately 2.5% resulted in decreased performance.

The decrease in performance observed for the negative control treatment compared to the corn-soybean meal positive control treatment in Exp. 3 indicated that dietary lysine levels likely were not above the pig's requirements. If diets had been formulated above the pig's requirement, greater quantities of L-lysine HCl could be added to diets before a second limiting amino acid would become limiting. The chemical analysis (Tables 7 and 8) of the diet samples for protein and amino

Table 6. Diet composition for pigs from 90 to 120 kg (Exp. 3 as-fed basis)

Ingredient, %	Negative control	L-lysine HCl, % 0	0.05	0.10	0.15	0.20	0.25	0.30	
Corn	82.24	78.45	79.82	81.20	82.67	84.03	85.41	86.78	
Soybean meal, 46.5% CP	9.32	13.16	11.72	10.29	8.74	7.30	5.87	4.43	
Choice white grease	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	
Monocalcium phosphate	1.08	1.05	1.05	1.05	1.05	1.08	1.08	1.08	
Limestone	0.85	0.83	0.85	0.85	0.88	0.88	0.88	0.90	
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	
Vitamin premix[a]	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	
Trace mineral premix[b]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	
L-lysine HCl	—	—	0.05	0.10	0.15	0.20	0.25	0.30	
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
Calculated analysis[c]									
Lysine, %	0.52	0.62	0.62	0.62	0.62	0.62	0.62	0.62	
Protein, %	11.3	12.8	12.2	11.7	11.1	10.5	10.0	9.3	
ME, Mcal/kg	3.60	3.60	3.60	3.60	3.59	3.59	3.59	3.58	
Total	Calculated amino acid ratios (%) relative to lysine[d]								*NRC*[e]
Methionine	39	36	35	33	32	31	30	29	27
Met + Cys	83	75	73	71	68	66	63	61	58
Threonine	80	76	72	69	**65**	**61**	**58**	**54**	68
Tryptophan	21	21	20	19	**17**	**16**	**14**	**13**	18
Isoleucine	76	75	70	66	61	57	**52**	**48**	55
Apparent digestible									
Methionine	46	40	39	37	35	34	32	31	28
Met + Cys	81	73	69	66	63	**59**	**56**	**53**	62
Threonine	79	73	69	65	**60**	**56**	**52**	**48**	64
Tryptophan	21	21	19	18	**16**	**14**	**13**	**11**	17
Isoleucine	84	81	75	69	64	58	**53**	**48**	55
True digestible									
Methionine	43	39	37	36	34	33	31	30	27
Met + Cys	79	71	68	65	62	**59**	**56**	**53**	60
Threonine	82	77	73	69	**64**	**60**	**56**	**52**	65
Tryptophan	23	23	21	19	**18**	**16**	**15**	**13**	19
Isoleucine	82	79	74	69	64	59	**54**	**49**	56

[a]Provided the following per kilogram of complete diet: vitamin A, 6,614 IU; vitamin D, 992 IU; vitamin E, 26.5 IU; menadione (menadione sodium bisulfate complex), 2.6 mg; vitamin B_{12}, 0.03 mg; riboflavin, 6.0 mg; pantothenic acid, 19.8 mg; and niacin, 33.1.
[b]Provided the following per kilogram of complete diet: Mn, 27 mg; Fe, 110 mg; Zn, 110 mg; Cu, 11 mg; I, 0.2 mg; and Se, 0.2 mg.
[c]Calculated values from NRC (1998) were used in diet formulation.
[d]Numbers in bold are calculated to be deficient compared to estimates of NRC (1998).
[e]NRC (1998) amino acid requirements for gilts from 80 to 120 kg with 325 g/d of lean accretion.

acids correlated closely to calculated values with a reasonable analytical variation (Cromwell et al., 1999). The unexpected increase in ADG and lack of decrease in G:F for the 0.30% L-lysine HCl treatment compared to the diet containing 0.25% L-lysine HCl treatment from 90 to 120 kg in Exp. 3 might be explained by the chemical analysis. The diet containing 0.30% L-lysine HCl had a slightly higher protein and amino acid profile than the 0.25% L-lysine HCl. The reason for this is not certain. All other amino acid levels agreed closely with calculated values.

Our results indicate that up to 0.15% L-lysine HCl can be used to replace the lysine from soybean meal in corn-soybean meal-based diets for growing-finishing pigs without resulting in a deficiency of another limiting amino acid. As the pigs become heavier, amino acid requirements change as well as the proportions of grain and soybean meal. Thus, in the corn-based diets methionine is potentially limiting during the grower phase which corresponds to 30 to 45 and 45 to 70 kg (Tables 3 and 4) phases in Exp. 3. However, in the later finisher phases, as used in Exp. 2 and the last two phases of Exp. 3, threonine or tryptophan become the potentially limiting amino acids. In Exp. 2, according to NRC (1998) requirement estimates, the diet with 0.15% L-lysine HCl should have been deficient in threonine and tryptophan from 63 to 80 kg and 80 to 109 kg, respectively, when amino acid ratios of the diet were calculated on a true digestible basis (Table 2). On an apparent digestible basis, the 0.15% L-lysine diet was calculated to be deficient in threonine from 63 to 80 kg and in threonine and tryptophan from 80 to 109 kg. On a total basis, the 0.15% L-lysine HCl was calculated to be deficient in threonine and tryptophan for both phases. In Exp. 3, the 0.15% L-lysine HCl treatment was calculated to be deficient in threonine and tryptophan in each of the four phases on total, apparent digestible, and true digestible bases according to NRC (1998; Tables 3 to 6). In addition, methionine was calculated to be deficient on a total basis and an apparent digestible basis during phase 1

Table 7. Crude protein and amino acid analysis (% of as-fed) of dietary treatments, Exp. 3

Item	Negative control	L-lysine HCl, %						
		0	0.05	0.10	0.15	0.20	0.25	0.30
30 to 45 kg								
CP	21.47	22.18	22.59	21.16	21.08	20.92	20.17	18.78
Lysine	1.24	1.29	1.35	1.31	1.30	1.32	1.33	1.28
Methionine	0.33	0.36	0.34	0.33	0.33	0.31	0.31	0.30
Met + Cys	0.69	0.73	0.72	0.70	0.70	0.65	0.65	0.63
Threonine	0.81	0.85	0.87	0.83	0.82	0.77	0.77	0.74
Tryptophan	0.31	0.26	0.27	0.29	0.25	0.24	0.23	0.21
Isoleucine	0.88	0.93	0.97	0.89	0.86	0.83	0.86	0.80
45 to 70 kg								
CP	17.84	19.38	19.64	18.74	18.36	17.58	16.85	16.82
Lysine	1.01	1.06	1.08	1.11	1.02	1.10	1.05	1.09
Methionine	0.29	0.31	0.31	0.29	0.28	0.27	0.25	0.27
Met + Cys	0.62	0.66	0.66	0.61	0.60	0.58	0.53	0.56
Threonine	0.69	0.73	0.75	0.71	0.68	0.66	0.62	0.66
Tryptophan	0.24	0.24	0.25	0.22	0.26	0.25	0.20	0.19
Isoleucine	0.78	0.80	0.78	0.77	0.63	0.73	0.65	0.67
70 to 90 kg								
CP	13.61	14.82	15.72	14.36	13.76	12.76	11.98	12.63
Lysine	0.74	0.77	0.85	0.84	0.85	0.83	0.76	0.82
Methionine	0.23	0.24	0.25	0.24	0.24	0.22	0.21	0.23
Met + Cys	0.50	0.51	0.54	0.52	0.51	0.47	0.44	0.49
Threonine	0.54	0.53	0.58	0.56	0.53	0.49	0.46	0.50
Tryptophan	0.14	0.15	0.18	0.16	0.16	0.18	0.10	0.12
Isoleucine	0.57	0.59	0.61	0.60	0.55	0.50	0.45	0.49
90 to 120 kg								
CP	10.63	12.07	11.81	11.21	10.68	9.66	9.42	9.62
Lysine	0.54	0.61	0.64	0.59	0.64	0.59	0.61	0.67
Methionine	0.18	0.22	0.21	0.20	0.19	0.19	0.17	0.18
Met + Cys	0.39	0.47	0.46	0.43	0.42	0.40	0.37	0.39
Threonine	0.40	0.46	0.47	0.43	0.42	0.37	0.34	0.36
Tryptophan	0.07	0.13	0.11	0.13	0.10	0.10	0.07	0.08
Isoleucine	0.41	0.46	0.48	0.42	0.41	0.31	0.33	0.38

(30 to 45 kg). According to the previous calculations, growth performance would be expected to be poorer because of amino acid deficiencies at L-lysine HCl additions lower than 0.15% during the first three phases of growth (Tables 3 to 5). Based on the growth performance observed in our experiments, either true or apparent digestible contents of threonine and tryptophan are underestimated in corn or the requirement estimates for threonine and tryptophan are overestimated.

According to Russell et al. (1986), tryptophan and threonine are equally the second limiting amino acids in corn-soybean meal diets. Our results suggest that the ratios relative to lysine requirement during the early growing-finishing period (30 to 45 kg) are not greater than 61 and 19%, 56 and 18%, and 59 and 20%, for threonine and tryptophan on a total, apparent digestible, and true digestible basis, respectively. The previous values are in accordance with the NRC (1998) estimates for tryptophan, but not threonine, for which higher ratios are suggested. For the late finishing period (90 to 120 kg), our results suggest that the ratios relative to lysine requirement are not greater than 65 and 17%, 60 and 16%, and 64 and 18%, for threonine and tryptophan on a total, apparent digestible, and true digestible basis, respectively. These values are lower than the estimates provided by the NRC (1998).

Methionine is considered the fourth limiting amino acid in corn-soybean meal diets for growing-finishing pigs. Additions of methionine to such diets supplemented with crystalline lysine, threonine, and tryptophan have been demonstrated to improve growth performance (Russell et al., 1983; Cromwell et al., 1983). The results from our experiment suggest that the ratios relative to lysine requirement during the early growing-finishing period (30 to 45 kg) are not greater than 53, 49, and 50% for methionine plus cystine on a total, apparent digestible and true digestible basis, respectively. Previous research in our laboratory (De la Llata et al., 1998) indicated a requirement estimate for growing pigs (10 to 25 kg) of 50% of lysine on an apparent digestible basis. However, the requirement estimates provided by the NRC (1998) are much higher (57%). From 45 to 70 kg, the present study indicates ratio requirements relative to lysine for sulfur amino acids not greater than 56, 52, and 52%, on a total, apparent digestible, and true digestible basis, respectively, compared to the NRC's estimate of 59%. From 70 to 90 kg, our results suggest ratio requirements no greater than

Table 8. Analyzed amino acid ratios (%) relative to lysine Exp. 3[a]

Item	Negative control	L-lysine HCl, %						
		0	0.05	0.10	0.15	0.20	0.25	0.30
30 to 45 kg								
Methionine	26.6	27.9	25.2	25.2	25.4	23.5	23.3	23.4
Met + Cys	55.6	56.6	53.3	53.4	53.8	49.2	48.9	49.2
Threonine	65.3	65.9	64.4	63.4	63.1	58.3	57.9	57.8
Tryptophan	25.0	20.2	20.0	22.1	19.2	18.2	17.3	16.4
Isoleucine	71.0	72.1	71.9	67.9	66.2	62.9	64.7	62.5
45 to 70 kg								
Methionine	28.7	29.2	28.7	26.1	27.5	24.5	23.8	24.8
Met + Cys	61.4	62.3	61.1	55.0	58.8	52.7	50.5	51.4
Threonine	68.3	68.9	69.4	64.0	66.7	60.0	59.0	60.6
Tryptophan	23.8	22.6	23.1	19.8	25.5	22.7	19.0	17.4
Isoleucine	77.2	75.5	72.2	69.4	61.8	66.4	61.9	61.5
70 to 90 kg								
Methionine	31.1	31.2	29.4	28.6	28.2	26.5	27.6	28.0
Met + Cys	67.6	66.2	63.5	61.9	60.0	56.6	57.9	59.8
Threonine	73.0	68.8	68.2	66.7	62.4	59.0	60.5	61.0
Tryptophan	18.9	19.5	21.2	19.0	18.8	21.7	13.2	14.6
Isoleucine	77.0	76.6	71.8	71.4	64.7	60.2	59.2	59.8
90 to 120 kg								
Methionine	33.3	36.1	32.8	33.9	29.7	32.2	27.9	26.9
Met + Cys	72.2	77.0	71.9	72.9	65.6	67.8	60.7	58.2
Threonine	74.1	75.4	73.4	72.9	65.6	62.7	55.7	53.7
Tryptophan	13.0	21.3	17.2	22.0	15.6	16.9	11.5	11.9
Isoleucine	75.9	75.4	75.0	71.2	64.1	52.5	54.1	56.7

[a]All other essential amino acids were in excess of 110% or greater of the ratio suggested by NRC (1998) for pigs with 325 g/day of lean accretion.

61, 56, and 56% on a total, apparent digestible, and true digestible basis, respectively. These results agree with the NRC (1998) only on a total basis. During the late finishing period (90 to 120 kg), our results indicate sulfur AA ratio requirements relative to lysine not greater than 68, 63, and 62% on a total, apparent digest-

Table 9. Growth performance and carcass characteristics of growing-finishing pigs fed increasing L-lysine HCl in sorghum-soybean meal-based diets, Exp. 1[a]

Item	L-lysine HCl, %				SEM	Probability ($P <$)	
	0	0.15	0.225	0.30		Linear	Quadratic
56 to 80 kg							
ADG, g	923	953	857	852	30	0.06	0.21
ADFI, kg	2.78	3.00	2.87	2.94	0.03	0.02	0.05
Gain:feed	0.33	0.32	0.30	0.29	0.01	0.01	0.57
80 to 114 kg							
ADG, g	904	882	765	739	26	0.01	0.22
ADFI, kg	3.42	3.55	3.53	3.52	0.07	0.32	0.38
Gain:feed	0.26	0.25	0.22	0.21	0.01	0.01	0.54
56 to 114 kg							
ADG, g	913	911	806	785	19	0.01	0.11
ADFI, kg	3.18	3.33	3.26	3.28	0.05	0.17	0.22
Gain:feed	0.29	0.27	0.25	0.24	0.01	0.01	0.38
Carcass characteristics[b]							
Carcass yield, %	64.0	65.0	64.1	63.0	0.4	0.83	0.06
Fat depth, mm[c]	14.4	16.1	17.3	18.7	0.5	0.01	0.40
Loin depth, mm	53.2	53.8	52.0	52.3	0.2	0.77	0.67
Fat-free lean index	51.1	50.3	49.7	48.8	0.3	0.01	0.22

[a]A total of 160 growing-finishing pigs were used. Values represent the means of 4 pens per treatment and 10 pigs per pen.

[b]Final weight was used as a covariate in the analysis of carcass data. Values are adjusted for differences in final weight.

[c]Skinned fat depth.

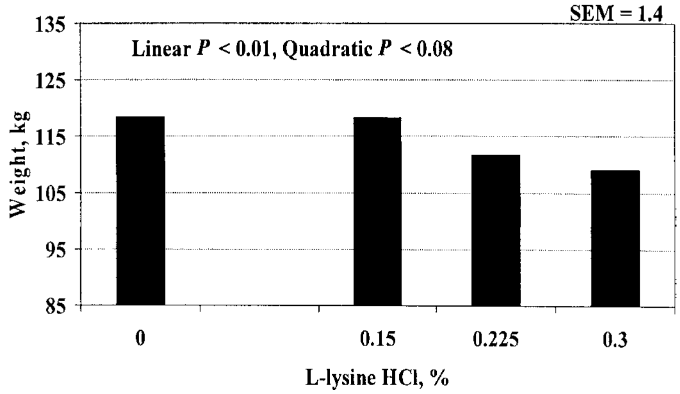

Figure 1. Final weight (kg) of growing-finishing pigs fed increasing L-lysine HCl in sorghum-soybean meal-based diets, Exp. 1. A total of 160 growing-finishing pigs were used. Values represent the means of 4 pens per treatment and 10 pigs per pen.

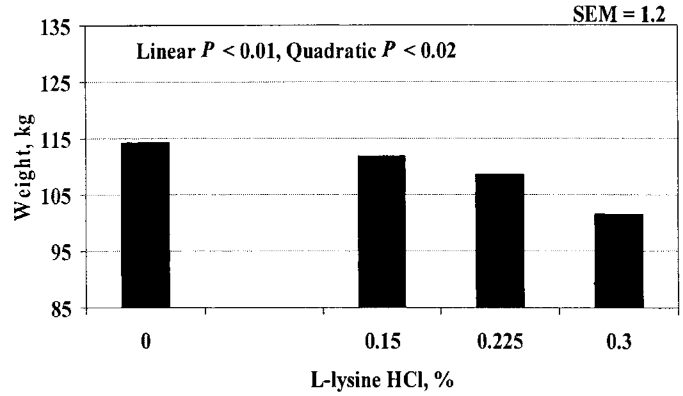

Figure 2. Final weight (kg) of growing-finishing pigs fed increasing L-lysine HCl in corn-soybean meal-based diets, Exp. 2. A total of 160 growing-finishing pigs were used. Values represent the means of 4 pens per treatment and 10 pigs per pen.

ible, and true digestible basis, respectively. These estimates are in agreement with those of the NRC (1998). However, the requirement may be much lower, because sulfur AA were likely not the first limiting in our study. Loughmiller et al. (1998) indicated that the requirement for sulfur AA on an apparent digestible basis was not greater than 50% for finishing gilts.

For our calculations, we used amino acid requirement estimates (NRC, 1998) for mixed gender pigs with a lean growth rate of 325 g/day of carcass fat-free lean. Pigs in our study grew at a lower lean growth rate and should have a slightly higher ratio requirement than that of our calculated comparisons. According to NRC (1998), pigs of the same weight range with a lower lean accretion rate would have higher ratio requirements relative to lysine for methionine, tryptophan, and threonine. Thus, the calculated ratio requirements for these amino acids could be slightly higher than the actual requirement.

According to Fuller et al. (1989) amino acid ratio requirements can be estimated in a factorial manner from the two major components of amino acid uses. The first is for that of protein deposition rate and the second for maintenance. Thus, the accuracy of these require-

Table 10. Growth performance and carcass characteristics of growing-finishing pigs fed increasing L-lysine HCl in corn-soybean meal-based diets, Exp. 2[a]

	L-lysine HCl, %					Probability (P <)	
Item	0	0.15	0.225	0.30	SEM	Linear	Quadratic
63 to 80 kg							
ADG, g	964	975	924	822	26	0.01	0.02
ADFI, kg	2.91	2.97	2.90	2.81	0.04	0.18	0.08
Gain:feed	0.33	0.33	0.32	0.29	0.01	0.01	0.02
80 to 109 kg							
ADG, g	927	862	796	643	33	0.01	0.05
ADFI, kg	3.33	3.18	3.21	2.87	0.05	0.01	0.01
Gain:feed	0.28	0.27	0.25	0.23	0.01	0.01	0.17
63 to 109 kg							
ADG, g	945	911	853	723	21	0.01	0.01
ADFI, kg	3.14	3.09	3.07	2.79	0.04	0.01	0.01
Gain:feed	0.30	0.29	0.28	0.26	0.001	0.01	0.03
Carcass characteristics[b]							
Carcass yield, %	64.2	64.3	65.2	64.3	0.6	0.74	0.60
Fat depth, mm[c]	15.5	15.0	15.0	17.2	1.3	0.73	0.32
Loin depth, mm	59.8	59.2	58.2	58.7	0.2	0.66	0.85
Fat-free lean index	50.1	50.2	50.5	49.8	0.7	0.86	0.54

[a]A total of 160 growing-finishing pigs were used. Values represent the means of 4 pens per treatment and 10 pigs per pen.

[b]Final weight was used as a covariate in the analysis of carcass data. Values are adjusted for differences in final weight.

[c]Skinned fat depth.

Table 11. Growth performance of growing-finishing gilts fed increasing L-lysine HCl in corn-soybean meal-based diets, Exp. 3[a]

		L-lysine HCl, %								Probability (*P* <)		
Item	Neg.	0.0	0.05	0.10	0.15	0.20	0.25	0.30	SEM	Neg. vs 0	Linear	Quadratic
30 to 45 kg												
ADG, g	764	804	817	799	805	770	778	765	17	0.10	0.02	0.59
ADFI, kg	1.40	1.39	1.40	1.39	1.40	1.43	1.42	1.43	0.02	0.87	0.10	0.86
Gain:feed	0.55	0.58	0.59	0.57	0.58	0.54	0.55	0.54	0.01	0.08	0.01	0.51
45 to 70 kg												
ADG, g	787	851	863	880	862	836	813	779	24	0.06	0.01	0.05
ADFI, kg	2.06	2.05	2.12	2.07	2.04	2.12	2.09	2.12	0.04	0.91	0.47	0.79
Gain:feed	0.38	0.42	0.41	0.43	0.42	0.39	0.39	0.37	0.01	0.02	0.01	0.02
70 to 90 kg												
ADG, g	772	827	845	828	822	774	735	741	20	0.04	0.01	0.13
ADFI, kg	2.12	2.15	2.13	2.15	2.12	2.14	2.15	2.22	0.04	0.57	0.34	0.15
Gain:feed	0.36	0.38	0.40	0.39	0.39	0.36	0.34	0.33	0.01	0.10	0.01	0.02
90 to 120 kg												
ADG, g	706	737	724	697	714	663	668	700	25	0.27	0.06	0.58
ADFI, kg	2.53	2.54	2.53	2.48	2.52	2.49	2.42	2.48	0.06	0.85	0.22	0.82
Gain:feed	0.28	0.29	0.29	0.28	0.28	0.27	0.28	0.28	0.01	0.34	0.21	0.28
30 to 120 kg												
ADG, g	753	800	809	796	797	757	746	742	11	0.01	0.01	0.20
ADFI, kg	2.04	2.06	2.07	2.04	2.04	2.06	2.02	2.07	0.02	0.89	0.74	0.52
Gain:feed	0.37	0.39	0.39	0.39	0.39	0.37	0.37	0.36	0.01	0.01	0.01	0.03

[a]A total of 1,200 growing-finishing gilts. Values represent the means of 6 pens per treatment and 25 pigs per pen.

ments depends on the accuracy of the maintenance requirement at different stages of growth and that for protein accretion. The responses in our study indicate that the ratio requirements for some amino acids may be overestimated for growing-finishing pigs.

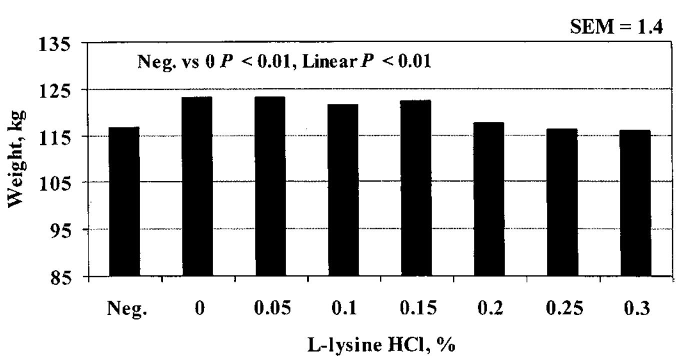

Figure 3. Final weight (kg) of growing-finishing gilts fed increasing L-lysine HCl in corn-soybean meal-based diets, Exp. 3. A total of 1,200 growing-finishing gilts. Values represent the means of 6 pens per treatment and 25 pigs per pen.

Implications

The results from these studies indicate that adding more than 0.15% L-lysine HCl to replace the lysine from soybean meal in sorghum- or corn-soybean meal-based diets in growing-finishing pigs leads to deficiencies in other amino acids that limit growth performance. It appears that the true digestibility coefficients for amino acids in sorghum may be overestimated in the tenth edition (1998) of the *Nutrient Requirements of Swine*. When feeding corn-based diets, values from the tenth edition (1998) of the *Nutrient Requirements of Swine* overestimate the methionine plus cystine, threonine, and tryptophan requirements relative to lysine for pigs from 30 to 90 kg.

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