MAXIMIZING CRYSTALLINE AMINO ACID USE IN DIETS FOR SWINE AND POULTRY

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INTRODUCTION

Increasing ingredient costs for diets continually results in the need to address different diet formulation options for the most cost effective production. Maximizing crystalline amino acid (AA) use in some instances may be the most cost effective production for broilers and pigs. Increasing crystalline AA has the effect of reducing dietary crude protein (CP) levels and improving overall nitrogen utilization by animals. This effect results in a reduction in the amount of nitrogen excreted in waste, in particular, nitrogen excreted as urea or uric acid.

Crystalline AA supplementation to reduced CP diets for broilers has been shown to reduce growth performance and carcass yield (Pinchasov et al., 1990; Bregendahl et al., 2002). Previous attempts to correct the negative growth effects of broilers fed low CP diets have been to modify the dietary electrolyte balance and supplement with non-protein nitrogen or AA, most of which have not been completely successful (see Aftab et al. [2006] for a comprehensive review). Essential or nonessential AA supplementation to reduced CP diets has been more successful. Corzo et al. (2004) reported that broilers fed an 18% CP diet with supplemental Gly or Leu had feed conversion ratio equal to that of broilers fed the control diet. Dean et al. (2006) also reported that broilers fed low CP, AA-supplemented diets had growth performance equal to broilers fed conventional corn-soybean (C-SBM) diets as long as crystalline Gly was supplemented.

Similarly, low CP, AA-supplemented diets (depending on the degree of CP reduction) for pigs oftentimes results in an increase in fat deposition with little or no change in growth performance (Knowles et al., 1998).

The purpose of this research was to determine the dietary concentration of the four commercially available crystalline AA that can be added to diets for broilers or growing pigs that will have no negative effect on growth production.

METHODS FOR BROILERS

Five experiments were conducted with male Ross × Ross 708 broilers from day 0 to 18 posthatching. Broilers were housed in temperature-controlled Petersime starter batteries with continuous fluorescent lighting. Feed in mash form and water were available on an ad libitum basis. Each treatment was replicated with 7 to 8 pens with 6 chicks per pen in completely randomized designs.

In all experiments, diets were C-SBM based and formulated to contain 1.26% total dietary Lys. The ratio of TSAA to Lys was set at 0.72, and the ratio of Thr to Lys was set at 0.70 in all diets. All experiments contained a positive control (PC) and a PC supplemented with crystalline Gly. The PC diet contained approximately 22.2% CP with no crystalline Gly or L-Lys•HCl in the diet. All diets except for the PC contained supplemental crystalline Gly to achieve 2.32% total dietary Gly + Ser, a level which previously has been shown to maximize growth performance of broilers fed low CP, AA-supplemented diets (Dean et al., 2006). Diets were formulated to contain 3,200 kcal ME/kg, 1.0% Ca, and 0.45% nonphytate P.

Experiments 1, 2, and 3 were conducted to determine the effect of incremental levels of L-Lys•HCl addition to diets on growth performance of broilers. In Exp. 1, in addition to the PC and negative control (NC) diets, Diets 3 to 9 had L-Lys•HCl added at 0.02% increments from 0.15 to 0.27% (Table 1). Experiment 2 was similar to Exp. 1 except Diets 3 to 10 had L-Lys•HCl added to the diets at 0.05% increments from 0.25 to 0.60%. Experiment 3 was conducted to confirm the results of Exp. 1 and 2. The treatment arrangement was identical to Exp. 1 and 2 except Diets 3 to 5 had L-Lys•HCl added at 0.05% increments from 0.20 to 0.30%.

Experiments 4 and 5 were conducted to determine the order of limiting AA other than Met, Thr, Lys, and Gly in low CP, C-SBM diets for broiler chicks. The treatments for Exp. 4 were 1) PC with 22.2% CP and no crystalline Gly or L-Lys•HCl added; 2) PC + 0.268% crystalline Gly; 3) NC with 0.45% L-Lys•HCl; 4) NC + 0.247% Ile; 5) NC + 0.484% L-Arg•HCl; 6) NC + 0.249% Val; 7) NC + 0.247% Ile + 0.484% Arg; 8) NC + 0.247% Ile + 0.249% Val; 9) NC + 0.249% Val + 0.484% Arg; 10) NC + 0.247% Ile + 0.484% Arg + 0.249% Val. Diets 2 to 10 contained supplemental crystalline Gly to provide a total dietary Gly + Ser level of 2.32%. Experiment 5 was conducted in an identical manner to Exp. 4 except the diets with the added crystalline AA contained the same ratio of corn to SBM that is found in a diet with 0.25% L-Lys•HCl, which was achieved by dilution with cornstarch. The ratio of Arg:Ile and Arg:Val changes from 1.54 and 1.35 to 1.55 to 1.38, respectively, between a diet with 0.45% L-Lys•HCl to a diet with 0.25% L-Lys•HCl. The ratios of Arg:Ile at 1.55 and Arg:Val at 1.38 that are in the 0.25% L-Lys•HCl diet are the same ratios that are found in the NC diet in Exp. 5.

Table 1. Composition of diets with incremental levels of L-Lys•HCl for broilers in Experiment 1, as-fed basis

			L-Lys•HCl (%)						
Ingredient	PC	PC + Gly	0.15	0.17	0.19	0.21	0.23	0.25	0.27
Corn	53.29	53.29	57.88	58.48	59.07	59.62	60.15	60.69	61.23
Soybean meal, 47.5%	37.13	37.13	32.82	32.25	31.68	31.11	30.54	29.97	29.40
Soy oil	4.93	4.93	4.34	4.26	4.19	4.13	4.08	4.02	3.96
Monocalcium phosphate	1.52	1.52	1.55	1.55	1.56	1.56	1.57	1.57	1.57
Limestone	1.48	1.48	1.51	1.51	1.51	1.51	1.52	1.52	1.52
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mineral mix	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Vitamin mix	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
D,L-Met	0.194	0.194	0.238	0.244	0.250	0.256	0.263	0.269	0.275
L-Lys•HCl	---	---	0.150	0.170	0.190	0.210	0.230	0.250	0.270
L-Thr	0.041	0.041	0.108	0.117	0.126	0.135	0.144	0.153	0.162
Gly	---	0.265	0.428	0.450	0.472	0.494	0.515	0.537	0.559
Cornstarch	0.559	0.294	0.131	0.119	0.110	0.126	0.148	0.170	0.191
Calculated composition									
ME, kcal/kg	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200
CP, %	22.21	22.52	21.26	21.08	20.90	20.72	20.53	20.35	20.16
Ca, %	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
P, %	0.72	0.72	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Non phytate P, %	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Cl, %	0.36	0.36	0.39	0.39	0.40	0.40	0.40	0.41	0.41
K, %	0.96	0.96	0.88	0.87	0.86	0.85	0.84	0.83	0.82
Lys, %	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26
Thr, %	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Gly+Ser, %	2.06	2.32	2.32	2.32	2.32	2.32	2.32	2.32	2.32
TSAA, %	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
Val, %	1.05	1.05	0.97	0.96	0.95	0.94	0.93	0.92	0.91
Arg, %	1.49	1.49	1.36	1.34	1.32	1.30	1.29	1.27	1.25
Ile, %	0.95	0.95	0.87	0.86	0.85	0.84	0.83	0.82	0.81

METHODS FOR PIGS

Four experiments were conducted to determine the effect of crystalline AA addition to diets for 20- to 40-kg pigs. Experiments 1 and 2 were conducted to determine the Lys requirement of the pigs used in this research. Experiment 3 was conducted to determine the level of crystalline Lys that results in reduced growth performance, and Experiment 4 was conducted to determine the order of limiting AA beyond Lys, Thr, Met, and Trp. Each treatment was replicated with 4 to 6 pens of 4 to 6 pigs per pen, and each experiment lasted 27 or 28 days. Grower pigs were housed in a totally enclosed building with metal slotted floors in 1.32 m x 2.44 m pens. Pigs were allotted to treatments on the basis of weight, sex, and ancestry in randomized complete block designs. All diets were formulated on a true ileal digestible (tid) basis and all AA were in ratio to tid Lys. Before allotment to treatment and at the termination of each experiment, blood was collected from each pig to determine plasma urea nitrogen (PUN) concentration. The first collection (PUN1) served as a baseline for the collection at the end of the experiment (PUN2).

In Exp. 1, pigs were fed C-SBM diets (Table 2) containing 0.830, 0.872, 0.913, or 0.955% tid Lys, which represent 0, 5, 10, and 15% above the NRC (1998) requirement. The Lys was provided by BioLys (50.7% Lys) and Met, Thr, and Trp were kept in a constant ratio to Lys. Experiment 2 was similar to Exp. 1 except the tid Lys levels were 0.747, 0.789, 0.830, 0.872, and 0.913%, which represent -10, -5, 0, 5, and 10% above the NRC (1998) requirement. From Exp. 1 and 2, the tid Lys requirement was determined. In Exp 3, all diets contained 0.83% tid Lys. The diets contained 0, 0.118, 0.191, 0.264, or 0.334% Lys from BioLys. According to NRC (1998), the diet with 0.264% added Lys was not deficient in any AA, but it exactly met the Ile:Lys ratio. However, the diet with 0.334% added Lys calculated to be deficient in both Val and Ile, but these AA were not added to the diet. In Exp. 4, the following diets were fed: 1) PC with 0% crystalline Lys; 2) Negative control (NC) with 0.334% Lys; 3) NC with 0.044% added Val; 4) NC with 0.021% added Ile; or 5) NC with 0.044% Val and 0.021% added Ile.

STATISTICS

For the broiler and pigs trials, data were statistically analyzed by ANOVA as a completely randomized designs (broiler) or randomized complete block designs (pig) using the GLM procedures in SAS (SAS Inst. Inc., Cary, NC). The pen of chicks or pigs was the experimental unit in all Exp. The PDIFF option of SAS was used to compare individual diets to each other, or contrasts statements were used.

Table 2. Composition of diets with incremental levels of L-Lys for pigs in Experiment 1, as-fed basis[1]

Ingredient, %	NRC tid Lys[2]	5% tid Lys	10% tid Lys	15% tid Lys
Corn	74.38	74.25	74.11	73.96
Soybean meal, 47.5 %	21.57	21.57	21.57	21.57
Monocalcium phosphate	1.18	1.183	1.184	1.19
Limestone	1.10	1.10	1.097	1.10
Salt	0.50	0.50	0.500	0.50
Sodium bentonite	0.50	0.50	0.500	0.50
Mineral mix	0.10	0.10	0.100	0.10
Vitamin mix	0.38	0.38	0.380	0.38
D,L-Met	0.029	0.055	0.080	0.106
Biolys[3]	0.233	0.316	0.398	0.481
L-Thr	0.029	0.057	0.084	0.112
L-Trp	--------	--------	0.004	0.012
Calculated composition				
ME, kcal/kg	3,240	3,240	3,241	3,241
CP,%	16.43	16.51	16.60	16.70
Ca, %	0.70	0.70	0.70	0.70
P, %	0.60	0.60	0.60	0.60
Lys, %	0.95	0.99	1.03	1.07
Met, %	0.288	0.314	0.339	0.364
Thr, %	0.641	0.669	0.696	0.723
Trp, %	0.187	0.187	0.192	0.199
tidLys, %	0.83	0.87	0.91	0.96
tidMet, %	0.26	0.29	0.31	0.34
tidThr, %	0.54	0.57	0.59	0.62
tidTrp, %	0.16	0.16	0.16	0.17
tidTSAA, %	0.50	0.52	0.55	0.57
tidVal, %	0.66	0.66	0.66	0.66
tidIle, %	0.58	0.58	0.58	0.58
tidArg, %	0.96	0.96	0.96	0.96
tidPhe + Tyr, %	1.17	1.17	1.17	1.17
tidLeu, %	1.29	1.28	1.28	1.28
tidHis, %	0.39	0.39	0.39	0.39

[1]Treatment diets are formulated to contain the same level of SBM that is in the control diet.

[2]The levels of tid Lys (0, 5, 10, and 15%) were chosen so that crystalline Val and Ile would not be deficient in the diet.

[3] Biolys (Degussa Corporation) contains 50.7% tid Lys.

RESULTS BROILERS

In Exp. 1 (Table 3), broilers fed the 0.21% or 0.23% L-Lys•HCl diets had an increased ADG and GF compared with broilers fed the PC diet ($P < 0.089$). The incremental L-Lys•HCl additions resulted in no detrimental effects on growth performance of broilers. Broilers fed the PC + Gly had increased GF compared with broilers fed the PC diet ($P = 0.064$).

Table 3. Growth performance of broiler chicks fed incremental levels of L-Lys•HCl in Experiment 1[1]

Treatment[2]	CP, %	ADG, g	ADFI, g	GF, g/g
1) Positive control (PC)	22.21	30.51	39.19	0.778
2) PC + Gly	22.52	31.30	39.23	0.798[3]
3) 0.15% L-Lys•HCl	21.26	31.73	40.23	0.789
4) 0.17% L-Lys•HCl	21.08	30.89	39.44	0.783
5) 0.19% L-Lys•HCl	20.90	31.82	40.28	0.790
6) 0.21% L-Lys•HCl	20.72	32.39[3]	40.67	0.797[3]
7) 0.23% L-Lys•HCl	20.53	32.05[3]	39.99	0.802[3]
8) 0.25% L-Lys•HCl	20.35	31.93	40.34	0.791
9) 0.27% L-Lys•HCl	20.16	31.33	39.74	0.789
	SEM	0.628	0.737	0.007
	P-value[4]	0.525	0.839	0.416
	Linear	0.738	0.988	0.474
	Quadratic	0.315	0.592	0.263

[1] Data are means of 8 pens of 6 broilers per pen.
[2] Crystalline Gly was added to each diet to achieve 2.32% Gly + Ser (Dean et al., 2006) except for Diet 1 (positive control).
[3] Significantly different ($P < 0.10$) from the positive control.
[4] Overall treatment P value.

In Exp. 2 (Table 4), broilers fed the 0.30%, 0.45%, or greater than 0.45% L-Lys•HCl levels had decreased ADG and ADFI compared with broilers fed the PC diet ($P < 0.042$). Broilers fed the 0.45% L-Lys•HCl and greater had decreased GF compared with broilers fed the PC diet ($P < 0.001$). Daily gain, ADFI, and GF were linearly reduced ($P < 0.001$) in broilers fed the incremental levels of L-Lys•HCl. As in Exp. 1, broilers fed the PC + Gly had increased GF compared with broilers fed the PC diet ($P < 0.010$).

In Exp. 3 (Table 5), broilers fed the 0.20 and 0.25% L-Lys•HCl diets had increased ADG compared with broilers fed the PC diet ($P = 0.067$). Broilers fed 0.30% L-Lys•HCl diet had increased ADFI compared with broilers fed the PC diet ($P < 0.093$). Gain:feed decreased linearly ($P < 0.065$) as the incremental levels of L-Lys•HCl increased from 0.20 to 0.30%. Also, broilers fed the PC + Gly had increased ADG and ADFI compared with broilers fed the PC diet ($P < 0.007$).

Table 4. Growth performance of broiler chicks fed incremental levels of L-Lys•HCl in Experiment 2[1]

Treatment[2]	CP, %	ADG, g	ADFI, g	GF, g/g
1) Positive control (PC)	22.19	27.67	37.08	0.745
2) PC + Gly	22.50	28.87	37.38	0.772[3]
3) 0.25% L-Lys•HCl	20.39	28.04	37.18	0.754
4) 0.30% L-Lys•HCl	19.97	25.81[3]	34.55[3]	0.747
5) 0.35% L-Lys•HCl	19.55	26.87	36.35	0.740
6) 0.40% L-Lys•HCl	19.12	26.45	36.06	0.734
7) 0.45% L-Lys•HCl	18.71	24.12[3]	34.08[3]	0.707[3]
8) 0.50% L-Lys•HCl	18.27	23.64[3]	33.92[3]	0.697[3]
9) 0.55% L-Lys•HCl	17.85	24.02[3]	34.34[3]	0.699[3]
10) 0.60% L-Lys•HCl	17.38	22.85[3]	33.45[3]	0.683[3]
	SEM	0.633	0.796	0.007
	P-value[4]	0.001	0.001	0.001
	Linear	0.001	0.001	0.001
	Quadratic	0.838	0.862	0.903

[1] Data are means of 7 pens of 6 broilers per pen.
[2] Crystalline Gly was added to each diet to achieve 2.32% Gly + Ser (Dean et al., 2006) except for treatment 1 (positive control).
[3] Significantly different ($P < 0.10$) from the positive control.
[4] Overall treatment P value.

Table 5. Growth performance of broiler chicks fed incremental levels of L-Lys•HCl in Experiment 3[1]

Treatment[2]	CP, %	ADG, g	ADFI, g	GF, g/g
1) Positive control (PC)	22.19	30.57	38.18	0.803
2) PC + Gly	22.50	33.55[3]	41.64[3]	0.805
3) 0.20% L-Lys•HCl	20.82	32.41[3]	39.85	0.814
4) 0.25% L-Lys•HCl	20.40	32.27[3]	39.90	0.810
5) 0.30% L-Lys•HCl	19.97	31.41	40.26[3]	0.781
	SEM	0.637	0.851	0.012
	P-value[4]	0.028	0.100	0.372
	Linear	0.276	0.735	0.065
	Quadratic	0.641	0.881	0.415

[1] Data are means of 8 pens of 6 broilers per pen.
[2] Crystalline Gly was added to each diet to achieve 2.32% Gly + Ser (Dean et al., 2006) except for treatment 1 (positive control).
[3] Significantly different ($P < 0.10$) from positive control.
[4] Overall treatment P value.

In Exp. 4 (Table 6), broilers fed the NC with the addition of Arg and Val or the NC with the addition of all 3 crystalline AA had increased ADG, ADFI, and GF ($P < 0.080$) compared to the broilers fed the NC. Broilers fed the PC or the PC + Gly had increased ADG, ADFI, and GF ($P < 0.011$) compared to the broilers fed the NC diet. Broilers fed the NC, NC + Ile, NC + Arg, NC + Val, NC + Ile + Arg, and NC + Ile + Val had reduced ADG and GF ($P < 0.004$) compared to the broilers fed the PC, but only broilers fed the NC + Ile or the NC + Val had decreased ADFI compared to the broilers fed the PC.

Table 6. Growth performance of broiler chicks to determine the 5th, 6th, and 7th limiting AA in Experiment 4[1]

Treatment[2]	ADG, g	ADFI, g	GF, g/g
1) Positive control (PC)	29.52[4]	37.04[4]	0.797[4]
2) PC+ Gly	29.96[4]	38.04[4]	0.788[4]
3) Negative control (NC) + Gly	24.67[3]	33.46[3]	0.737[3]
4) NC + Gly + Ile	24.36[3]	32.76[3]	0.743[3]
5) NC + Gly + Arg	26.31[3]	35.35	0.744[3]
6) NC + Gly + Val	24.63[3]	34.15[3]	0.723[3]
7) NC + Gly + Ile + Arg	26.30[3]	35.22	0.747[3]
8) NC + Gly + Ile + Val	25.63[3]	34.79	0.736[3]
9) NC + Gly + Val + Arg	27.84[4]	35.89[4]	0.776[3,4]
10) NC + Gly + Ile + Val + Arg	28.72[4]	36.35[4]	0.790[3]
SEM	0.762	0.964	0.008
P-value[5]	0.001	0.008	0.001

[1] Data are means of 7 pens of 6 broilers per pen.
[2] Crystalline Gly was added to each diet to achieve 2.32% Gly + Ser (Dean et al., 2006) except for treatment 1 (positive control).
[3] Significantly different ($P < 0.10$) from positive control.
[4] Significantly different ($P < 0.10$) from the negative control.
[5] Overall treatment P value.

In Exp. 5 (Table 7), broilers fed the NC + Val +Arg had increased ADG ($P < 0.035$) compared to the broilers fed the NC. Broilers fed the NC + all 3 crystalline AA had increased ADG and GF ($P < 0.022$) compared to the broilers fed the NC. Broilers fed the PC or PC + Gly had increased ADG, ADFI, and GF ($P < 0.059$) compared to the broilers fed the NC. Broilers fed the NC or NC + individual or any combination of the 3 crystalline AA had decreased ADG and GF ($P < 0.034$) compared to the broilers fed the PC, except the GF for the broilers fed the NC + all 3 crystalline AA had the same GF as the broilers fed the PC. Broilers fed the NC, NC + Ile, NC + Ile + Arg, NC + Ile + Val, or the NC + all 3 crystalline AA had decreased ADFI ($P < 0.072$) compared to broilers fed the PC.

Table 7. Growth performance of broiler chicks to determine the 5th, 6th, and 7th limiting AA in Experiment 5 [1]

Treatment	ADG, g	ADFI, g	GF, g/g
1) Positive control (PC)	28.88[3]	37.36[3]	0.775[3]
2) PC + Gly	28.75[3]	37.35[3]	0.770[3]
3) Negative control (NC) + Gly	24.74[2]	35.06[2]	0.706[2]
4) NC + Gly + Ile	24.90[2]	34.65[2]	0.718[2]
5) NC + Gly + Arg	25.20[2]	36.13	0.698[2]
6) NC + Gly + Val	25.06[2]	35.87	0.700[2]
7) NC + Gly + Ile + Arg	24.58[2]	34.52[2]	0.712[2]
8) NC + Gly + Ile + Val	25.14[2]	35.19[2]	0.715[2]
9) NC + Gly + Val + Arg	26.71[2,3]	36.79	0.726[2]
10) NC + Gly + Ile + Val + Arg	26.89[2,3]	34.71[2]	0.775[3]
SEM	0.648	0.840	0.013
P-value[4]	0.001	0.103	0.001

[1] Data are means of 7 pens of 6 broilers per pen.
[2] Significantly different ($P < 0.10$) from positive control.
[3] Significantly different ($P < 0.10$) from the negative control.
[4] Overall treatment P value.

The results of Exp. 1 to 3 indicate that 0.25% L-Lys·HCl can be added to broiler diets formulated to provide 1.26% total Lys with no detrimental effects on growth performance, as long as Gly is included in the diets. Dean et al. (2006) also reported that broilers fed low CP, AA-supplemented diets had growth performance equal to broilers fed conventional C-SBM diets as long as crystalline Gly was supplemented. However, the 16% CP diet they used was not considered practical because it contained additional crystalline AA other than the commercially available AA. The level of total Lys used in our diets was 1.26%, which may be below the requirement for Ross × Ross 708 broilers. If the 1.26% Lys is below the requirement, then the actual level of L-Lys•HCl that can be added will be greater than 0.25%.

Experiments 4 and 5 suggest that Val and Arg are equally limiting growth performance of broilers fed diets containing greater than 0.25% L-Lys•HCl. The concentrations of Val and Arg in the 0.25% L-Lys•HCl diet were 0.97 and 1.32, respectively. The ratios of Arg:Lys and Val:Lys in the 0.25% L-Lys•HCl diet were 1.05 and 0.77, respectively. Thus, if one sets these minimums in diet formulation, growth performance should not be affected.

In conclusion, supplementation of 0.25% L-Lys•HCl to a C-SBM will support broiler growth performance equivalent to broilers fed a C-SBM diet with 22% CP as long as crystalline Met, Thr, and Gly are supplemented. Arginine and Val are equal limiting after Met, Lys, Thr, and Gly in a diet with 0.25% L-Lys•HCl.

RESULTS PIGS

In Exp. 1, ADG and ADFI were not affected by Lys addition, but GF of pigs fed the Lys addition 10% in excess of NRC was greater than the pigs fed the NRC tid Lys requirement (Table 8). Plasma urea nitrogen was not affected by diet. The results of Exp. 2 show that the Lys levels below the NRC (1998) requirement are deficient; however, as in Exp. 1, there was no response to Lys addition above the NRC requirement of 0.83% tid Lys. Broken-line analysis of the PUN and ADG data indicate tid Lys requirement of 0.82 and 0.84%, respectively. Based on the results of Exp. 1 and 2, it was decided that the subsequent research would be conducted with diets formulated to provide 0.83% tid Lys.

In Exp. 3 (Table 9), ADG and GF of pigs fed the diet containing 0.334% added Lys from BioLys was significantly reduced compared with pigs fed the control diet. Although, the effect was not significant, pigs fed the diet containing 0.264% crystalline Lys tended to have reduced ADG compared with pigs fed the control diet. These results suggest that the diet with 0.334% added Lys is deficient in another one or more AA, which is in agreement with the NRC recommendations. Thus, Exp. 4 was conducted to determine which AA was limiting in the diet with 0.334% added Lys. During the first 14 days of Exp. 4, ADG indicated that Ile was more limiting than Val (Table 10). Daily gain of pigs fed the diet with added Val tended to be reduced compared with that of pigs fed the NC diet while the Ile addition tended to improve ADG. Gain of pigs fed the combination of Ile and Val was not different from that of pigs fed the PC diet, but both ADG and GF tended to be lower in pigs fed the combination of these two AA than in pigs fed the PC diet. This response suggests that an AA other than Ile and Val may be limiting growth. The 14 to 28 day data and the overall data suggest that both Ile and Val are equaling limiting; a response to the individual additions of each of these AA did not occur. However, ADG of pigs fed the combination of AA was not different from that of pigs fed the PC diet, but again, both ADG and GF were lower than that of pigs fed the control diet, suggesting that another AA may be limiting growth.

The results of this research indicate that the tid Lys requirement of 20 to 40-kg pigs is 0.83% of the diet, which agrees with the NRC requirement estimate. The results also indicate that 0.191% crystalline Lys can be added to this diet with no negative effects on growth performance. Pigs fed the diet with 0.264% crystalline Lys had growth performance that was not significantly different from the PC diet, but there was a tendency for reduced gain and efficiency. Pigs fed the diet with 0.334% crystalline Lys had reduced growth performance, which could be completely overcome with Ile and Val addition. Isoleucine and Val are nearly equally limiting in this diet.

Table 8. Growth performance and plasma urea nitrogen (PUN) of pigs fed different levels of lysine and other amino acids in Experiments 1 and 2

Experiment 1[1]					
	NRC tid Lys	5% tid Lys	10% tid Lys	15% tid Lys	SEM
ADG, g	729.0	714.5	776.9	724.0	23.5
ADFI, g[2]	1,737	1,641	1,663	1,717	36
GF, g/g[2]	0.419	0.437	0.467[5]	0.422	0.011
28-day BW, kg	44.2	43.8	45.6	44.0	0.7
PUN, mg/dL	7.07	6.69	6.25	6.86	0.41
Experiment 2[3]						

	10% below tid Lys	5% below tid Lys	NRC tid Lys	5% above tid Lys	10% above tid Lys	SEM
ADG, g[4]	678.4[5]	697.7[5]	741.4	741.4	744.5	16.2
ADFI, g	1,620	1,700	1,680	1,656	1,704	38
GF, g/g[4]	0.420	0.411[5]	0.441	0.449	0.437	0.10
28-day BW, kg[4]	38.37[5]	38.93[5]	40.27	40.15	40.26	0.47
PUN, mg/dL	9.07	8.52	8.05	8.58	8.88	0.45

[1]Data are means of 4 replications of 6 pigs per pen (3 barrows and 3 gilts). Initial BW 23.77 ± 3.10 kg.
[2] Quadratic effect ($P < 0.10$).
[3]Data are means of 6 replications of 6 pigs per pen (3 barrows and 3 gilts). Initial BW 19.42 ± 3.13 kg.
[4]Linear effect ($P < 0.10$).
[5]Significantly different ($P < 0.10$) from positive control.

Table 9. Growth performance and plasma urea nitrogen (PUN) of pigs fed different levels of crystalline lysine and other amino acids in Experiment 3[1]

	0% Lys	0.118% Lys	0.191% Lys	0.264% Lys	0.334% Lys	SEM
ADG, g[2]	739.0	714.0	739.8	708.1	662.8[4]	17.5
ADFI, g	1,632	1,620	1,616	1,630	1,696	35
GF, g/g[2,3]	0.457	0.443	0.460	0.435	0.392[4]	0.010
27-day BW, kg	43.99	43.19	43.99	43.35	42.28[4]	0.60
PUN, mg/dL[3]	11.14	8.55[4]	6.54[4]	4.73[4]	3.19[4]	0.40

[1]Data are means of 4 replications of 5 pigs per pen (reps 1 and 2 had 3 barrows and 2 gilts; reps 3 and 4 had 2 barrows and 3 gilts). Initial BW 24.13 ± 3.88 kg.
[2]Linear effect ($P < 0.10$).
[3] Quadratic effect ($P < 0.10$).
[4]Significantly different ($P < 0.10$) from positive control.

Table 10. Growth performance and plasma urea nitrogen (PUN) of pigs fed different levels of amino acids in Experiment 4[1]

	PC	NC	NC+Val	NC+Ile	NC+Val+Ile	SEM
Initial BW, kg	20.32[a]	20.31[a]	20.19[a]	20.39[a]	20.07[a]	0.131
14 day BW, kg	29.57[a]	28.85[a,b]	28.38[b]	29.05[a,b]	28.92[a,b]	0.308
28 day BW, kg	40.98[a]	39.42[b]	38.91[b]	39.39[b]	39.90[a,b]	0.434
Growth performance						
Day 0 to 14						
ADG, g	660.95[a]	609.92[a,b]	585.22[b]	618.83[a,b]	632.19[a,b]	24.62
ADFI, g	1307.32[c]	1358.75[a,b,c]	1346.20[b,c]	1408.77[a,b]	1456.36[a]	40.02
GF, g/g	0.506[a]	0.428[b]	0.434[b]	0.441[b]	0.440[b]	0.014
Day 14 to 28						
ADG, g	814.85[a]	754.64[b]	752.07[b]	738.30[b]	784.07[a,b]	19.48
ADFI, g	1706.03[a,b,c]	1691.25[b,c]	1639.01[c]	1743.50[a,b]	1795.54[a]	40.27
GF, g/g	0.480[a]	0.446[b,c]	0.460[a,b]	0.424[c]	0.437[b,c]	0.013
Overall						
ADG, g	737.90[a]	682.28[b]	668.64[b]	678.57[b]	708.13[a,b]	16.80
ADFI, g	1506.68[b]	1519.63[b]	1492.60[b]	1576.13[a,b]	1625.95[a]	33.68
GF, g/g	0.492[a]	0.437[b]	0.448[b]	0.431[b]	0.436[b]	0.011
PUN, mg/dL	11.60[a]	3.13[b]	2.85[b]	3.48[b]	3.61[b]	0.404

[1]Data are means of 4 replications of 4 pigs per pen (1 gilt and 3 barrows).
[a,b,c]Means with different superscripts within a row are significantly different ($P < 0.10$).

LITERATURE CITED

Aftab, U., M. Ashraf, and Z. Jiang. 2006. Low protein diets for broilers. Worlds Poult. Sci. J. 62: 688-698.

Bregendahl, K., J. L. Sell, and D. R. Zimmerman. 2002. Effect of low-protein diets on growth performance and body composition of broiler chicks. Poult. Sci. 81:1156-1167.

Corzo, A., C. A. Fritts, M. T. Kidd, and B. J. Kerr. 2004. Response of broiler chicks to essential and non-essential amino acid supplementation of low crude protein diets. Anim. Feed Sci. Technol. 118:319-327.

Dean, D. W., T. D. Bidner, and L. L. Southern. 2006. Glycine supplementation to low protein, amino acid-supplemented diets supports optimal performance of broiler chicks. Poult. Sci. 85:288-296.

Knowles, T. A., L. L. Southern, T. D. Bidner, B. J. Kerr and K. G. Friesen. 1998. Effect of dietary fiber or fat in low crude protein, crystalline amino acid-supplemented diets for finishing pigs. J. Anim. Sci. 76:2818-2832.

Pinchasov, Y., C. X. Mendonca, and L. S. Jensen. 1990. Broiler chick response to low protein diets supplemented with synthetic amino acids. Poult. Sci. 69:1950-1955.