EVALUATION OF COMPENSATORY GAIN, STANDARDIZED ILEAL DIGESTIBLE LYSINE REQUIREMENT, AND REPLACING SPECIALTY PROTEIN SOURCES WITH CRYSTALLINE AMINO ACIDS ON GROWTH PERFORMANCE OF NURSERY PIGS

by

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B.S., North Carolina State University, 2009

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Animal Sciences and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2011

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Abstract

A total of 5,212 nursery pigs were used in 11 experiments to evaluate amino acids in nursery pig diets.

Experiments 1 and 2 were conducted to determine whether the Lys level fed during one phase of the nursery influenced the response to Lys during subsequent phases. Experiment 1 tested a wide range of dietary Lys in 2 phases and reported that pigs fed high Lys during each period had increased growth performance; however, compensatory growth occurred for the pigs previously fed low Lys diets, resulting in no impact on overall ADG or final BW. Experiment 2 tested a narrow range of dietary Lys in 3 phases and found that marginally deficient diets can be fed in the early nursery phases without influencing final BW or the response to Lys levels in subsequent phases. Both experiments demonstrate that the low dietary Lys levels used in each can be fed in the early nursery phases with no negative impact on overall nursery growth rate provided that adequate levels are fed thereafter.

Experiments 3 to 6 were conducted to determine the standardized ileal digestible (SID) Lys requirement of nursery pigs from 7- to 14-kg. Data from all experiments were combined and break-point and quadratic broken-line analysis was used to determine the estimated SID Lys requirement. The SID Lys requirement for optimal growth was at least 1.30% for ADG and 1.37% for G:F, or at least 3.86 and 4.19 g SID Lys/Mcal ME, respectively.

Experiments 7 to 11 were conducted to evaluate the effect of replacing specialty protein sources with crystalline AA and AA requirements for 7- to 12-kg pigs. Experiment 7 demonstrated that crystalline AA can be used to replace fish meal in diets with no negative effects on growth performance. Experiment 8 demonstrated that L-Trp, L-Val, and a source of non-essential AA were needed in low-CP, AA-fortified nursery diets to achieve maximum growth performance, whereas the addition of L-Ile was not required. Experiment 9 indicated that feeding greater than 7.35% total Lys:CP decreased growth performance and Exp. 10 indicated that a SID Val:Lys ratio of 65% was sufficient for optimal growth of early nursery pigs. Implementing the results from the previous experiments, Exp. 11 determined that crystalline AA in nursery pigs diets can replace high amounts of fish meal, meat and bone meal, and poultry meal when balanced for minimum AA ratios and maximum Lys:CP with no negative effect on growth performance.

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Acknowledgements

First and foremost I would like to thank my family for the unconditional love and support that they have given me over the years. None of this would have been possible without the guidance of my parents (Gene and Susan Nemechek) and my sisters (Sarah, Molly, and Megan). I know I can always count on my family to be there for me day in and day out. In addition to my immediate family, there have also been other special family members who have supported me during the past few years. Moving halfway across the country to start at a new university is not an easy thing to do. My cousin Manda, her husband J.C., and their 3 kids Cadence, Raina, and Trevor have let me live at their house during my time as a graduate student. Words cannot explain the joys I get every day being able to come home to such a fun and loving family. I truly am blessed.

Over the past 2 years, I have also had the privilege of working with an amazing group of professors. There is no one else that I would rather learn from than the "Swine Team" at KSU, made up of Dr. Tokach, DeRouchey, Nelssen, Goodband, and Dritz. The amount of time and effort that these professors invest into their students is second to none. They strive daily to ensure that we are provided with all the tools we need to become respected researchers and successful swine nutritionists. I understand that the knowledge I can gain at KSU is limitless, and I look forward to continuing my education under such an amazing and passionate group of professors.

I've also realized that inspiration not only comes from professors, but even more so from friends. There's no way I could have made it through the past 2 years without the support and especially the comic relief provided by all my friends and fellow graduate students - Jon, Megan, Rommel, Jay, Nick, Chad, Julie, Mandy, Hyatt, Eddie, Sue, Kelly, Matt, Josh, Christina, Harold, Miguel, Brandon, Chris, Devin, and Jackie. Thank you all for the amazing times we've shared, and know there are many more to come.

Chapter 1 - Effect of standardized ileal digestible lysine on growth and subsequent performance of nursery pigs

ABSTRACT

Two experiments were conducted to determine whether the Lys level fed during one phase of the nursery influenced the response to Lys during subsequent phases. In Exp. 1 (294 nursery pigs, initially 6.28 kg ± 0.09 kg BW), 6 dietary treatments were arranged in a 3 × 2 factorial. From d 0 to 14, pigs were fed diets with 1.14% standardized ileal digestible (SID) Lys, 1.53% SID Lys with 30% soybean meal and high crystalline AA, or 1.53% SID Lys with 33.2% soybean meal and low crystalline AA. From d 14 to 28, the 2 dietary treatments were 1.20 or 1.40% SID Lys. From d 0 to 14, increasing SID Lys from 1.14 to 1.53% increased ($P < 0.002$) ADG and G:F. Of the 1.53% treatments, pigs fed the diet with low soybean meal had increased ($P < 0.05$) ADG compared to those fed the high soybean meal diet. From d 14 to 28, pigs previously fed high Lys diets had decreased ($P < 0.02$) ADG and ADFI compared to pigs fed 1.14% SID Lys from d 0 to 14. Increasing the SID Lys level from 1.20 to 1.40% from d 14 to 28 increased ($P < 0.01$) ADG and G:F and decreased ($P < 0.04$) ADFI. Due to the compensatory growth from d 14 to 28, treatment diets during either period had no impact on overall ADG or final BW. In Exp. 2 (320 weanling pigs, initially 5.71 kg ± 0.05 kg BW), 8 dietary treatments were arranged in a 2 × 2 × 2 factorial. Pigs were fed either 1.35 or 1.55% SID Lys during phase 1 (d 0 to 7), 1.15 or 1.35% SID Lys in phase 2 (d 7 to 21), and 1.05 or 1.25% SID Lys during phase 3 (d 21 to 35). The low dietary Lys concentrations were achieved by reducing both crystalline Lys and intact protein sources from the high Lys diets. From d 0 to 7, increasing SID Lys improved ($P < 0.01$) G:F, but there were no differences in ADG or ADFI. Similarly, from d 7 to 21, there were no differences in ADG or ADFI between pigs fed the two Lys levels, but increasing SID Lys improved ($P < 0.03$) G:F. During phase 3, feeding the high Lys diet increased ($P < 0.01$) ADG and G:F, but had no effect on ADFI. For the overall trial (d 0 to 35), pigs fed the high Lys level during phase 3 had the greatest improvement ($P < 0.03$) in ADG and G:F. There were no dietary interactions between phases, indicating that the Lys level fed in each phase did not influence the response to Lys in subsequent phases. In conclusion, both experiments demonstrate that the low dietary Lys levels can be fed in the early nursery phases with no negative impact on overall nursery growth rate provided that adequate levels are fed thereafter.

Key Words: compensatory growth, lysine, nursery pig, phase feeding

INTRODUCTION

Increasing Lys and other essential AA from deficient to adequate levels has been shown to improve daily gain and feed efficiency (Gaines et al., 2003; Kendall et al. 2008; Nemechek et al. 2011). However, these gains have not always been maintained throughout subsequent phases when common diets were fed, indicating a compensatory gain effect for those previously fed the AA deficient diets (Thaler et al., 1986; Chiba, 1994; Fabian et al., 2004). The reason for compensatory gain to occur in some trials but not in others (Chiba et al., 1999, 2002) is not fully understood. Suggested explanations for the variability among trials includes the degree of AA restriction and the length of time that pigs are subject to the restriction (Prince et al., 1983; Kamalakar et al. 2009). Also, inconsistencies have been shown to occur among different phases in production. Chiba (1995) found that pigs compensated from deficiencies fed during the grower phase, but not from deficiencies fed during the starter phase. The majority of compensatory gain research has been focused on the grower and finisher phases. Limited research has been conducted to investigate compensatory gain within different phases within the nursery phase.

In addition to growth performance, diet costs are important considerations for nursery pigs. Dritz et al. (1996) and Mahan et al. (2004) suggested that increasing diet complexity improves growth performance in early nursery pigs. In an effort to achieve increased complexity, nursery diets are often formulated with a maximum limit on soybean meal and contain increased levels of expensive specialty protein sources (fish meal, poultry meal, blood co-products, etc.), especially in early nursery phases (Stoner et al., 1990; Keegan et al., 2004; Pierce et al., 2005). Lowering dietary Lys would allow for reduced use of specialty protein sources and thus decreased diet costs in the early nursery period. Therefore, the objectives of these experiments was to: 1) determine whether the dietary Lys level fed during one nursery phase influenced the response to Lys during subsequent nursery phases and 2) whether level of dietary Lys reduction (major; Exp. 1 or marginal; Exp. 2) influences the response.

MATERIALS AND METHODS

All experimental procedures and animal care were approved by the Kansas State University Institutional Animal Care and Use Committee.

Experiment 1

A total of 294 nursery pigs (PIC TR4 × 1050, Hendersonville, TN, initially 6.28 kg ± 0.09 kg BW) were used in a 28-d growth trial to determine whether feeding major reductions in dietary Lys influenced growth performance during the subsequent nursery phase. Pigs were weaned at approximately 21 d of age and fed a common pelleted starter diet for 3 d. At weaning, pigs were allotted to pens by initial BW to achieve the same average weight for all pens. On d 3 after weaning, pens were allotted randomly to 1 of 6 dietary treatments. Thus, d 3 after weaning was d 0 of the experiment. There were 7 pigs per pen and 7 pens per treatment. Each pen (1.22 × 1.52 m) contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. The trial was conducted at the Kansas State University Swine Teaching and Research Center.

A 2-phase diet series was used with phase 1 diets fed from d 0 to 14 and phase 2 diets fed from d 14 to 28. All 6 experimental diets were corn-soybean meal-based (Table 1.1), with 3 diets fed during phase 1 and 2 Lys levels fed during phase 2. On d 0, pigs were assigned both the phase 1 and phase 2 dietary treatments, and were therefore not re-allotted within treatment on d 14. From d 0 to 14, pigs were fed either 1.14 or 1.53% SID Lys, with all diets containing 10% spray-dried whey and 4.5% select menhaden fish meal. Wide differences in standardized ileal digestible (SID) Lys were used in an effort to ensure differences in growth performance. Two different methods of formulation were used to achieve the 1.53% SID Lys level. One 1.53% SID Lys diet was formulated to contain 30% soybean meal, equal to the soybean meal level of the 1.14% SID Lys diet, and was supplemented with high amounts of crystalline AA (L-Lys·HCl, DL-Met, L-Thr, L-Ile, L-Trp, L-Val, L-Gln, and L-Gly). In the second 1.53% SID Lys diet, soybean meal was increased to 33.15% and crystalline L-Lys·HCl, DL-Met, L-Thr, and L-Val were included at low levels. During the second phase (d 14 to 28), the two dietary treatments were 1.20% or 1.40% SID Lys. The 1.40% SID Lys level was achieved by increasing soybean meal and L-Lys·HCl only. Nutrients and SID AA digestibility values used for diet formulation were obtained from NRC (1998). All experimental diets were in meal form and were prepared at the Kansas State University Animal Science Feed Mill. Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and G:F.

Experiment 2

A total of 320 weanling pigs (PIC 1050 barrows, initially 5.71 ± 0.05 kg BW) were used in a 35-d growth trial to determine whether feeding minor reductions in dietary Lys influenced growth performance during the subsequent nursery phases. At weaning, pigs were weighed and allotted to 1 of 8 dietary treatments. There were 5 pigs per pen and 8 pens per treatment. Each pen (1.22 × 1.22 m) contained a 4-hole, dry self-feeder and a cup waterer to provide ad libitum access to feed and water. The trial was conducted at the Kansas State University Segregated Early Weaning Facility.

A 3-phase diet series was used, with phase 1 diets fed from d 0 to 7, phase 2 diets from d 7 to 21, and phase 3 diets from d 21 to 35 after weaning. For each phase, pigs were fed 1 of 2 Lys levels. The SID Lys levels were 1.35 or 1.55% during phase 1 (d 0 to 7), 1.15 or 1.35% in phase 2 (d 7 to 21), and 1.05 or 1.25% during phase 3 (d 21 to 35; Table 1.2). All 8 experimental diets were corn-soybean meal-based, and the lower dietary Lys concentrations were achieved by reducing both crystalline Lys and intact protein sources (Table 1.3). Lactose level was kept equal within each phase at 12, 7, and 0% for phase 1, 2, and 3, respectively. Nutrients and SID AA digestibility values used for diet formulation were obtained from NRC (1998). Phase 1 diets were fed in pelleted form and prepared at the Kansas State University Grain Science Feed Mill, while phase 2 and phase 3 diets were fed in meal form and prepared at the Kansas State University Animal Science Feed Mill. Pigs and feeders were weighed on d 0, 7, 14, 21, 28, and 35 after weaning to calculate ADG, ADFI, and G:F.

Statistical Analysis

Pen was the experimental unit for data analysis in both experiments. Both experiments were analyzed using the MIXED procedure in SAS (SAS Institute, Inc., Cary, NC). In Exp. 1, a 2 × 3 arrangement was used in a completely randomized design. In Exp. 2, a 2 × 2 × 2 factorial arrangement was used in a split-split plot design. Both models included dietary treatments and their interactions as fixed effects. Least square means were evaluated using the PDIFF option of SAS, with significant differences declared at $P < 0.05$ and trends declared at $P < 0.10$.

RESULTS

Experiment 1

From d 0 to 14, increasing the SID Lys increased ($P < 0.002$) ADG, decreased ($P < 0.003$) ADFI, and increased ($P < 0.001$) G:F (Table 1.4). When comparing growth performance of pigs fed the two 1.53% SID Lys diets, pigs fed the diet with high crystalline AA and low soybean meal had increased ($P < 0.05$) ADG compared to the pigs fed the diet with high soybean meal. There was no difference in ADFI or G:F between the 2 treatments. There was also an unexpected difference ($P < 0.03$) in ADG and G:F during phase 1 as a result of phase 2 Lys levels. This was due to pigs fed lower Lys levels in the subsequent period from d 14 to 28 having slightly higher ADG from d 0 to 14 than pigs fed higher Lys in phase 2.

During phase 2 (d 14 to 28), pigs previously fed the high Lys diets from d 0 to 14 had decreased ($P < 0.02$) ADG and ADFI compared to the pigs fed 1.14% SID Lys from d 0 to 14. Lysine level fed from d 0 to 14 had no impact on G:F from d 14 to 28. There was no difference in ADG or ADFI from d 14 to 28 in the pigs previously fed the two different 1.53% SID Lys diets; however, there was a trend for increased ($P < 0.07$) G:F during phase 2 in pigs fed the 1.53% SID Lys level with higher soybean meal during phase 1 compared to pigs fed the high crystalline AA, lower soybean meal diet. Also, increasing the SID Lys from 1.20 to 1.40% during this phase increased ($P < 0.01$) ADG and G:F and decreased ($P < 0.04$) ADFI.

Overall (d 0 to 28), there were no interactions between phases during any of the feeding periods. Phase 1 Lys level had no impact on ADG for the entire trial, but the response to ADFI and G:F carried over into the overall data resulting in decreased ($P < 0.001$) ADFI and increased ($P < 0.001$) G:F for pigs fed the 1.53% SID Lys diets from d 0 to 14. There was no difference in overall ADG, ADFI, or G:F between the pigs fed 2 1.53% SID Lys diets with different soybean meal levels. The Lys level fed during phase 2 had no impact on overall ADG. However, due to the response to ADFI and G:F during phase 2, there was a trend in the overall data for decreased ($P < 0.08$) ADFI and increased ($P < 0.001$) G:F for the pigs fed 1.40% SID Lys from d 14 to 28.

Experiment 2

For phase 1 (d 0 to 7), there were no differences in ADG or ADFI between pigs fed the 2 dietary SID Lys levels (1.35 or 1.55%); however, increasing Lys increased ($P < 0.01$) G:F (Table 1.5). Because the low Lys level was adequate for ADG and ADFI but not G:F, this suggests that SID Lys of 1.35% was marginally deficient during phase 1.

During phase 2 (d 7 to 21), there were no differences in ADG or ADFI for pigs fed the two dietary SID Lys levels (1.15 or 1.35%). Also consistent with the phase 1 response, pigs fed the high Lys diet during the second period had increased ($P < 0.03$) G:F when compared to the pigs fed the low Lys diet. The Lys levels fed during phase 1 did not influence the results of phase 2. Similar to the response in phase 1, the low Lys level fed during phase 2 appears to be marginally deficient, based on the differences in G:F.

During phase 3 (d 21 to 35), the high Lys diet increased ($P < 0.01$) ADG and G:F; however, the increase in Lys did not affect ADFI. The Lys level fed during any of the previous phases did not influence performance during phase 3.

For the overall trial (d 0 to 35), there were no interactions between dietary Lys levels for ADG or final BW. Pigs fed the high Lys level during phase 3 had increased ($P < 0.03$) ADG and G:F compared to those fed the low level during this phase. Increasing dietary Lys during phase 2 also tended ($P < 0.07$) to increase overall G:F. Consistent with the data from the previous phases, increasing the Lys level during any phase did not influence overall ADFI.

DISCUSSION

The Lys requirements of nursery pigs estimated by the NRC (1998) are categorized in 2 weight ranges. For 5 to 10 kg pigs, NRC (1998) estimates the SID Lys requirement to be 1.19%. More recent research suggested that the NRC (1998) estimates are too low, and indicate that the SID Lys requirement of similar BW pigs is between 1.30 and 1.42% (Gaines et al., 2003; Dean et al., 2007; Nemechek et al., 2011). Based on these estimates, the SID Lys levels fed in Exp. 1 were formulated to 1.14 or 1.53% for pigs between 6 to 10 kg (d 0 to 14) to ensure Lys was below and above the pigs requirement. Increasing SID Lys improved ADG and G:F, which was consistent with the design of the experiment, validating that 1.14% SID Lys was deficient. The SID Lys levels in Exp. 2, on the other hand, were formulated to a more narrow range. From 5.7 to 7 kg BW (d 0 to 7), pigs were fed either 1.35 or 1.55% SID Lys. From 7 to 12 kg BW (d 7 to 21), pigs were fed SID Lys levels of either 1.15 or 1.35%. The increase in G:F without a response in ADG would indicate that the low Lys diets were marginally deficient in both phases, as studies have demonstrated that the Lys requirement for G:F is greater than the requirement for ADG (Gaines et al., 2003; Nemechek et al., 2011).

For 10 to 20 kg pigs, NRC (1998) estimates the SID Lys requirement to be 1.01%. Similar to lighter pigs, recent research suggest the optimal SID Lys estimates range from 1.30 to 1.40% SID Lys (Lenehan et al., 2003; Kendall et al., 2008). Data from the present trials agree with the higher Lys requirement estimations. In Exp. 1, feeding a SID Lys level of 1.20% from 10 to 17 kg BW decreased ADG and G:F compared to pigs fed 1.40% SID Lys. In Exp. 2, decreasing the SID Lys level from 1.25 to 1.05% during the final phase (12 to 20 kg BW) decreased ADG and G:F. The response to SID Lys levels in both trials confirms that the Lys requirements of nursery pigs are higher than NRC (1998) values.

In Exp. 1, despite the increased ADG in pigs fed high Lys during each period, there was no difference in ADG among treatments for the overall trial (d 0 to 28). The similarity in gains was primarily a result of compensatory gain during the second period for pigs previously fed the low SID Lys. There were no interactions between phases, meaning that compensatory gain occurred regardless of Lys level fed in phase 2. In agreement, other publications confirm that pigs are capable of improvements in growth when diets are realigned to meet AA requirements after a period of AA restriction; however, research on compensatory gain is limited primarily to the grower and finisher phases (Thaler et al., 1986; Chiba, 1995; Fabian et al., 2002). Chiba (1995) investigated compensatory gain responses among the starter, grower, and finisher phases, but experimental diets were kept constant during the nursery phase. Thus, the response to Lys level of phases within the nursery was not established.

Although the mechanism behind compensatory growth in swine is not fully understood, Prince et al. (1983) and Kamalakar et al. (2009) suggested that the degree of AA restriction and the length of time that pigs are subject to the restriction may influence compensatory gain response. In Exp. 1, the compensatory gain during the second period appears to be driven primarily by increased feed intake. However, Chiba (1994) and Fabian et al. (2004) also observed compensatory gain after a period of Lys restriction without differences in ADFI, meaning that other factors contributed to the gain. Zimmerman and Khajarern (1973) suggested that compensatory gain may result from changes in metabolism caused by dietary treatment, such as increased levels and activity of the enzymes involved in protein turnover rates. In agreement, Chiba (1994) and Noblet et al. (1987) reported that increasing dietary AA results in metabolic or physiological changes, indicated by increased internal organ weights for pigs fed higher dietary AA. Based on this information, increased feed intake may not be the sole reason for the response shown in the current trial. Conversely, the response in nursery pigs may be due to different mechanism than the compensatory response in finishing pigs. Further research is needed to determine the causes of compensatory growth in nursery pigs.

In Exp. 2, pigs were fed much closer to their requirements for SID Lys which resulted in a response to G:F, and not to ADG. The lack of a gain response did not allow pigs the opportunity to express compensatory gain. However, this experiment demonstrates that marginally deficient diets can be fed in the earlier nursery phases without influencing final BW or the response to SID Lys levels in subsequent phases. Although the influences of SID Lys levels within each phase on overall G:F were not as significant in Exp. 2, the response in Exp. 1 and trend in Exp. 2 shows that the compensatory gain response was in ADG and not G:F. Thus, any diet cost savings that may arise from feeding lower Lys levels must overcome the lower G:F associated with those levels.

In addition to dietary Lys, diet complexity also has an effect on nursery pig performance (Chiba, 1995). Although this was not the focus of our research, there were complexity differences in Exp. 2 diets, because intact protein sources were increased to achieve the high Lys diets. Thus diet complexity changed, particularly in the diets fed from d 0 to 7. Mahan et al. (2004) reported numerical differences in growth performance between feeding semicomplex or complex diets for the first 2 wk after weaning. In a similar experiment, Dritz et al. (1996) fed 3 levels of diet complexity (low, medium, or high) to nursery pigs of different ages. From d 0 to 7 after weaning, feeding the low complexity diet decreased growth performance, but there was no difference in ADG or G:F between the pigs fed medium or high complexity diets. Experiment 2 diets fed from d 0 to 7 in our experiment are comparable to the medium and high complexity diets fed by Dritz et al. (1996). Therefore, in agreement with Mahan et al. (2004) and Dritz et al. (1996), the response to feed efficiency in the current trial was most likely not influenced by the minor differences in diet complexity.

In Exp. 1, there was also a difference in ADG between pigs fed the different 1.53% SID Lys levels. Pigs fed the high soybean meal diet, had decreased ADG compared to those fed the low soybean meal. The difference in growth may be due to the increase in soybean meal, which causes a hypersensitivity response in early-weaned pigs (Li et al., 1990, 1991). However, because the difference in soybean meal between the diets was minor, it is more likely that the growth response was a result of a slight Trp deficiency in the higher soybean meal diet. The low soybean meal diet contained 18.2%

SID Trp:Lys. In contrast, the high soybean meal diet contained 15.7% SID Trp:Lys, which has been suggested to be deficient by others (NRC, 1998; Susenbeth, 2006).

In conclusion, both experiments indicate that lower dietary Lys levels can be fed in the early nursery phases without negative impact on overall ADG or BW, as long as diets during the late nursery period are adequate in Lys. Allowing for formulation of lower Lys diets in early nursery phases could result in an economical advantage by reducing feed costs while maintaining optimal growth performance. There were no interactions between phases in either experiment, which indicate that the response to Lys in one phase is not influenced by the Lys level fed in other phases.

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FIGURES AND TABLES

Table 1.1 Composition of diets, Exp. 1 (as-fed-basis)[1]

		Phase 1 (d 0 to 14)			Phase 2 (d 14 to 21)	
Item	SID Lysine, %:	1.14	1.53 Low Soybean meal	1.53 High Soybean meal	1.20	1.40
Ingredient, %						
Corn		52.30	50.15	48.30	63.45	57.95
Soybean meal (46.5% CP)		30.00	30.00	33.15	32.40	37.70
Spray-dried whey		10.00	10.00	10.00	---	---
Select menhaden fish meal		4.50	4.50	4.50	---	---
Soybean oil		1.00	1.00	1.00	---	---
Monocalcium phosphate (21% P)		0.55	0.55	0.525	1.075	1.025
Limestone		0.55	0.55	0.55	0.95	0.95
Salt		0.30	0.30	0.30	0.35	0.35
Zinc oxide		0.25	0.25	0.25	---	---
Trace mineral premix[2]		0.15	0.15	0.15	0.15	0.15
Vitamin premix[3]		0.25	0.25	0.25	0.25	0.25
L-Lys·HCl		---	0.50	0.40	0.31	0.40
DL-Met		0.055	0.30	0.23	0.13	0.20
L-Thr		---	0.26	0.20	0.13	0.18
L-Trp		---	0.055	---	---	---
L-Ile		---	0.10	---	---	---
L-Val		---	0.22	0.095	---	0.05
L-Gln		---	0.40	---	---	---
L-Gly		---	0.40	---	---	---
Medication[4]		---	---	---	0.70	0.70
Phytase[5]		0.085	0.085	0.085	0.125	0.125
TOTAL		100	100	100	100	100
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lys		1.14	1.53	1.53	1.20	1.40
Ile:Lys		70	58	55	59	57
Leu:Lys		140	103	108	123	114
Met:Lys		36	43	39	36	38
Met & Cys:Lys		60	60	58	58	58
Thr:Lys		65	65	64	64	64
Trp:Lys		19.7	18.2	15.7	17.2	16.6
Val:Lys		75	70	65	65	65
Total Lys, %		1.28	1.66	1.67	1.33	1.54
ME, kcal/kg		3,360	3,377	3,369	3,289	3,294
SID Lys:ME, g/Mcal		3.39	4.52	4.53	3.66	4.25
CP, %		22.0	23.9	23.9	20.5	22.8
Ca, %		0.74	0.74	0.74	0.69	0.70
P, %		0.68	0.67	0.68	0.63	0.64
Available P, %		0.48	0.48	0.48	0.42	0.41

[1]A total of 294 nursery pigs (PIC TR4 × 1050, initially 5.71 ± 0.05 kg) were used in a 28-d trial to determine

whether the Lys level fed during one phase influenced the response to Lys during subsequent phases.

[2]Trace mineral premix provided per kg of complete feed: 16.5 mg of Cu from $CuSO_4 \cdot 5H^20$, 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$, 165 mg of Fe as $FeSO_4H_2O$, 39.7 mg of Mn as $MnSO_4 \cdot H20$, 0.30 mg of Se as Na_2SeO_3, and 165 mg of Zn as $ZnSO_4$.

[3]Vitamin premix provided per kg of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B_{12}, 50.0 mg of niacin, 27.6 mg of pantothenic acid, and 8.3 mg of riboflavin.

[4]Neo/Oxy 10/10 (Penfield Animal Health, Omaha, NE)

[5]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 510 FTU/kg, with a release of 0.10% available P.

Table 1.2 Dietary treatments (Exp. 2)[1]

	Standardized ileal digestible lysine, %							
d 0 to 7	1.35	1.35	1.35	1.35	1.55	1.55	1.55	1.55
d 7 to 21	1.15	1.15	1.35	1.35	1.15	1.15	1.35	1.35
d 21 to 35	1.05	1.25	1.05	1.25	1.05	1.25	1.05	1.25

[1]A total of 320 weanling pigs (PIC 1050 barrows, initially 5.71 ± 0.05 kg and 21 d of age) were used in a 35-d trial with 8 pens per treatment. Phase 1, 2, and 3 diets were fed from d 0 to 7, 7 to 21, and 21 to 35 after weaning, respectively.

Table 1.3 Composition of diets, Exp. 2 (as-fed-basis)[1]

Item	Phase 1 (d 0 to 7)		Phase 2 (d 7 to 21)		Phase 3 (d 21 to 35)	
	Low	Normal	Low	Normal	Low	Normal
Ingredient, %						
Corn	45.73	41.26	54.83	48.56	61.36	54.92
Soybean meal (46.5% CP)	9.50	11.61	18.27	23.69	19.80	26.20
Spray-dried animal plasma	5.50	6.70	---	---	---	---
Spray-dried whey	25.00	25.00	10.00	10.00	---	---
Distillers dried grains with solubles	---	---	10.00	10.00	15.00	15.00
Select menhaden fish meal	4.90	6.00	3.50	4.50	---	---
Spray-dried blood cells	1.35	1.65	---	---	---	---
Soybean oil	5.00	5.00	---	---	---	---
Monocalcium phosphate (21% P)	0.45	0.20	0.43	0.28	0.80	0.75
Limestone	0.50	0.45	0.75	0.65	1.15	1.10
Salt	0.25	0.25	0.30	0.30	0.35	0.35
Zinc oxide	0.38	0.38	0.25	0.25	---	---
Vitamin premix[2]	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15
L-Lys·HCl	0.15	0.15	0.33	0.35	0.40	0.45
DL-Met	0.12	0.15	0.05	0.10	0.04	0.09
L-Thr	0.04	0.05	0.08	0.10	0.08	0.11
Medication[4]	0.70	0.70	0.70	0.70	0.50	0.50
Phytase[5]	---	---	0.13	0.13	0.13	0.13
Vitamin E, 20,000 IU	0.05	0.05	---	---	---	---
Total	100.00	100.00	100.00	100.00	100.0	100.00
Calculated analysis						
Standardized ileal digestible (SID) amino acids, %						
Lys	1.35	1.55	1.15	1.35	1.05	1.25
Ile:Lys	50	49	61	60	60	60
Leu:Lys	127	123	139	131	152	140
Met:Lys	30	31	31	33	31	32
Met & Cys:Lys	56	56	57	57	59	58
Thr:Lys	62	62	62	62	62	62
Trp:Lys	17	17	16	16	16	16
Val:Lys	70	70	69	67	72	69
Total Lys , %	1.48	1.69	1.29	1.50	1.19	1.40
CP, %	20.2	22.7	19.7	22.4	19.0	21.5
ME, kcal/kg	3,497	3,510	3,280	3,287	3,303	3,305
Ca, %	0.77	0.77	0.70	0.71	0.68	0.67
P, %	0.71	0.72	0.62	0.64	0.58	0.60
Available P, %	0.53	0.53	0.36	0.37	0.31	0.30

[1]A total of 320 weanling pigs (PIC 1050 barrows, initially 5.71 ± 0.05 kg and 21 d of age) were used in a 35-d trial with 8 pens per treatment. Phase 1, 2, and 3 diets were fed from d 0 to 7, 7 to 21, and 21 to 35 after weaning, respectively.

[2]Vitamin premix provided per kg of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B_{12}, 50.0 mg of niacin, 27.6 mg of pantothenic acid, and 8.3 mg of riboflavin.

[3]Trace mineral premix provided per kg of complete feed: 16.5 mg of Cu from $CuSO_4 \cdot 5H^20$, 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$, 165 mg of Fe as $FeSO_4H_2O$, 39.7 mg of Mn as $MnSO_4 \cdot H20$, 0.30 mg of Se as Na_2SeO_3, and 165 mg of Zn as $ZnSO_4$.

[4]Neo/Oxy 10/10 (Penfield Animal Health, Omaha, NE).

[5]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 750 FTU/kg, with a release of 0.11% available P.

Table 1.4 Effects of lysine level in each phase on nursery pig performance (Exp. 1)[1]

	Standardized ileal digestible lysine, %							Probability, *P* <			
									Phase 1		Phase 2
Phase 1:	1.14	1.14	1.53 Low SBM[2]	1.53 Low SBM[2]	1.53 High SBM[3]	1.53 High SBM[3]		Phase 1 × Phase 2	1.14 vs. 1.53%	1.53% low SBM vs. 1.53% high SBM	1.20 vs 1.40%
Phase 2:	1.20	1.40	1.20	1.40	1.20	1.40	SEM				
d 0 to 14											
ADG, g	239	217	271	247	242	244	7.88	0.20	0.002	0.05	0.03
ADFI, g	354	335	327	323	305	313	10.06	0.40	0.003	0.12	0.53
G:F	0.677	0.652	0.830	0.769	0.795	0.779	0.019	0.45	< 0.001	0.51	0.03
d 14 to 28											
ADG, g	510	539	468	512	485	506	14.44	0.72	0.02	0.72	0.01
ADFI, g	764	729	720	694	708	682	16.94	0.95	0.004	0.49	0.04
G:F	0.668	0.739	0.649	0.740	0.685	0.742	0.01	0.27	0.97	0.07	< 0.001
d 0 to 28											
ADG, g	374	378	370	380	364	375	9.46	0.90	0.62	0.56	0.29
ADFI, g	559	532	523	508	506	498	11.75	0.72	0.001	0.25	0.08
G:F	0.670	0.711	0.706	0.749	0.718	0.753	0.01	0.92	< 0.001	0.38	< 0.001
BW, kg											
d 0	6.23	6.35	6.30	6.25	6.28	6.28	0.09	0.68	0.90	0.95	0.77
d 14	9.58	9.39	10.09	9.72	9.67	9.70	0.14	0.38	0.02	0.13	0.13
d 28	16.72	16.93	16.65	16.89	16.46	16.78	0.29	0.98	0.62	0.61	0.29

[1]A total of 294 nursery pigs (PIC TR4 × 1050, initially 6.28 kg ± 0.09 kg) were used in a 28-d trial with 7 pens per treatment. Phase 1 diets were fed from d 0 to 14 and phase 2 diets were fed from d 14 to 28.
[2]Diet was formulated to 1.53% SID Lys and contained 30% soybean meal, 10% spray-dried whey, and 4.5% select menhaden fish meal. The diet was also supplemented with high amounts of crystalline AA including L-Lys·HCl, DL-Met, L-Thr, L-Trp, L-Ile, L-Val, L-Gln, and L-Gly to achieve minimum AA ratios.
[3]Diet was formulated to 1.53% SID Lys and contained 33.15% soybean meal, 10% spray-dried whey, and 4.5% select menhaden fish meal. Supplemented crystalline AA included L-Lys·HCl, DL-Met, L-Thr, and L-Val.

Table 1.5 Effects of lysine level fed during each phase on nursery pig performance (Exp. 2)[1]

	Standardized ileal digestible lysine, %									Probability, $P <$						
d 0 to 7	1.35	1.35	1.35	1.35	1.55	1.55	1.55	1.55		Phase 1 ×						
d 7 to 21	1.15	1.15	1.35	1.35	1.15	1.15	1.35	1.35		Phase 2 ×	Phase 1 ×	Phase 2 ×	Phase 1 ×			
d 21 to 35	1.05	1.25	1.05	1.25	1.05	1.25	1.05	1.25	SEM	Phase 3	Phase 2	Phase 3	Phase 3	Phase 1	Phase 2	Phase 3
d 0 to 7																
ADG, g	161	151	152	162	155	163	159	161	19.9	0.38	0.98	0.68	0.74	0.69	0.89	0.72
ADFI, g	171	164	157	164	145	150	149	162	15.0	0.83	0.32	0.47	0.53	0.37	0.94	0.55
G:F	0.962	0.926	0.965	0.997	1.054	1.089	1.074	0.984	0.059	0.12	0.19	0.64	0.68	0.01	0.93	0.63
d 7 to 21																
ADG, g	363	365	366	371	346	333	370	375	15.8	0.73	0.27	0.59	0.74	0.41	0.18	0.98
ADFI, g	541	530	512	521	508	506	498	517	18.4	0.95	0.46	0.43	0.72	0.16	0.49	0.78
G:F	0.674	0.687	0.716	0.711	0.680	0.660	0.742	0.723	0.016	0.63	0.29	0.66	0.24	0.75	0.03	0.43
d 21 to 35																
ADG, g	561	616	579	614	555	573	540	593	35.1	0.23	0.89	0.75	0.65	0.20	0.78	0.001
ADFI, g	934	915	943	956	907	883	883	925	34.6	0.59	0.76	0.12	0.70	0.37	0.53	0.85
G:F	0.601	0.674	0.614	0.643	0.613	0.649	0.612	0.640	0.031	0.29	0.82	0.12	0.27	0.60	0.39	<.0001
d 0 to 35																
ADG, g	402	422	406	426	389	395	395	419	11.3	0.55	0.57	0.55	0.77	0.15	0.30	0.03
ADFI, g	745	726	730	747	711	701	696	732	20.5	0.86	0.88	0.14	0.60	0.38	0.74	0.65
G:F	0.645	0.692	0.666	0.683	0.658	0.676	0.681	0.688	0.011	0.48	0.42	0.12	0.13	0.52	0.07	0.001
BW, kg																
d 0	5.71	5.70	5.73	5.68	5.71	5.75	5.71	5.71	0.05	0.92	0.46	0.11	0.05	0.59	0.24	0.43
d 7	6.84	6.76	6.79	6.81	6.80	6.89	6.83	6.83	0.19	0.38	0.89	0.96	0.45	0.67	0.91	0.85
d 21	11.93	11.86	11.95	12.00	11.67	11.55	12.01	12.09	0.32	0.92	0.31	0.66	0.97	0.54	0.14	0.94
d 35	19.78	20.64	20.05	20.59	19.44	19.57	19.57	20.38	0.36	0.38	0.57	0.75	0.68	0.14	0.37	0.04

[1]A total of 320 weanling pigs (PIC 1050 barrows, initially 5.71 ± 0.05 kg and 21 d of age) were used in a 35-d trial with 8 pens per treatment. Phase 1, 2, and 3 diets were fed from d 0 to 7, 7 to 21, and 21 to 35 after weaning, respectively.

Chapter 2 - Evaluation of standardized ileal digestible lysine requirement of nursery pigs from 7- to 14-kg

ABSTRACT

Four experiments were conducted to determine the standardized ileal digestible (SID) Lys requirement of nursery pigs from 7- to 14-kg. In Exp. 1, 294 pigs (PIC TR4 × 1050, 6.76 ± 0.08 kg BW) were used in a 28-d growth trial at the Kansas State University Swine Teaching and Research Center, with 7 pigs per pen and 7 pens per treatment. Treatment diets were fed from d 0 to 14 and a common diet was fed from d 14 to 28. The 6 SID Lys levels tested were 1.15, 1.23, 1.30, 1.38, 1.45, and 1.53%. Treatment diets were corn-soybean meal-based with 10% spray-dried whey and 4.5% fish meal and contained 3.37 Mcal of ME/kg. From d 0 to 14, ADG and ADFI increased (quadratic; $P < 0.002$) as SID Lys increased from 1.15 to 1.30%, with no further increase at higher levels. Feed efficiency improved (linear; $P < 0.001$) with increasing SID Lys. Experiments 2 to 4 were each 14-d growth trials conducted in commercial nurseries, with treatment diets containing 1.22, 1.32, 1.42, 1.52, or 1.62% SID Lys. Diets were corn-soybean meal-based with 3.45 Mcal of ME/kg. Soybean meal and lactose were kept constant in all treatment diets at 30% and 7% of the diet, respectively. Diets contained 5% fish meal and 0.88% spray-dried blood cells in Exp 2 and 4 and 6.67% fish meal in Exp. 3. In Exp. 2, 840 pigs (PIC 337 × C22, initially 7.6 ± 0.13 kg) were used with 24 pigs per pen and 7 pens per treatment. Increasing SID Lys from 1.22 to 1.42% increased (quadratic; $P < 0.01$) ADG and G:F, with no further improvement for pigs fed the 1.52 or 1.62% SID Lys diets. There was no difference in ADFI. In Exp. 3, 1,260 pigs (PIC 337 × C22, initially 8.5 ± 0.14 kg) were used with 42 pigs per feeder and 6 feeders per treatment. Increasing dietary Lys increased (quadratic; $P < 0.02$) ADG and G:F with the greatest response as SID Lys increased from 1.22 to 1.32% with smaller further responses to 1.42 and 1.52%. There was no difference in ADFI with increasing SID Lys. In Exp. 4, 770 pigs (PIC TR4 × C22, initially 7.4 ± 0.07 kg) were used with 22 pigs per pen and 7 pens per treatment. Increasing SID Lys increased (quadratic; $P < 0.05$) ADG, with pigs fed 1.32 and 1.42% SID Lys diets having the numerically greatest gains. Increased SID Lys, decreased (linear; $P < 0.001$) ADFI and increased (quadratic; $P < 0.02$) G:F. In conclusion, our experiments suggest that NRC (1998) Lys recommendations (1.19% SID Lys) are lower than required for optimal growth for 5- to 10-kg pigs. Break point analysis indicated that the SID Lys requirement for optimal growth was at least 1.30% for ADG and 1.37% for G:F, or at least 3.86 and 4.19 g SID Lys/Mcal ME, respectively.

Key Words: amino acids, growth, lysine, pig

INTRODUCTION

Lysine is the first limiting AA in corn-soybean meal diets for pigs and is used as a reference point to estimate requirements of other essential AA. The NRC (1998) dietary recommendation for 5- to 10-kg pigs is approximately 1.35% total Lys or 1.19% standardized ileal digestible (SID) Lys with the range of research estimates reported in NRC (1998) varying widely from 1.10 to 1.40% total Lys. Other research has reported a greater total Lys requirement for 5- to 14-kg pigs of 1.45 to 1.49% (Gatel et al., 1992; Broekman et al., 1997). In a more recent report, Dean et al. (2007) suggested that 1.40% SID Lys is required for optimal growth of 6- to 12-kg pigs.

Similar conclusions have been made from experiments with heavier nursery pigs. The current recommendation by NRC (1998) for 10- to 25-kg pigs is 1.15% total Lys or 1.01% SID Lys; however, recent studies with pigs of this weight range have found the requirement to be between 1.30 and 1.40% SID Lys (Lenehan et al., 2003; Hill et al., 2007; Kendall et al., 2008). Research with 25- to 120-kg pigs has also indicated that NRC (1998) recommendations may be too low (De La Llata et al., 2007; Main et al., 2008) for modern genotypes.

Many factors can contribute to the variation in Lys estimates including formulating on a total instead of SID amino acid basis (Stein et al., 2007), methods of statistical analysis (Robbins et al., 2006), gender (Baker, 1996), or genotype (Schneider et al., 2010). In addition, all previous research on Lys requirements of early nursery pigs has been conducted in university research settings and not under commercial field conditions. Therefore, our objective was to evaluate the SID Lys requirement for nursery pigs from 7- to 14-kg in both university (Exp. 1) and commercial facilities (Exp. 2 to 4).

MATERIALS AND METHODS

All experimental procedures and animal care were approved by the Kansas State University Institutional Animal Care and Use Committee.

Experiment 1

A total of 294 nursery pigs (PIC TR4 × 1050, 6.76 ± 0.08 kg BW) were used in a 28-d growth trial at the Kansas State University Swine Teaching and Research Center. Pigs were weaned at approximately 21 d of age and fed a common starter diet (1.56% SID Lys) for 3 d. At weaning, pigs were allotted to pens by initial BW to achieve the same average weight for all pens. On d 3 after weaning, pens were allotted to 1 of 6 dietary treatments in a completely randomized design. Thus, d 3 after weaning was d 0 of the experiment. There were 7 pigs per pen and 7 pens per treatment. Each pen (1.22 × 1.52 m) contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water.

A 2-phase diet series was used, with treatment diets fed from d 0 to 14 and a common diet fed from d 14 to 28 (Table 2.1). The 6 SID Lys treatments fed from d 0 to 14 were 1.15, 1.23, 1.30, 1.38, 1.45, and 1.53%. Treatment diets were corn-soybean meal based, contained 10% spray-dried whey and 4.5% select menhaden fish meal and were formulated to 3.37 Mcal of ME/kg. Soybean meal and L-Lys·HCl both increased to attain the higher SID Lys diets. Crystalline DL-Met, L-Thr, L-Trp, L-Ile, and L-Val also increased with increasing SID Lys to maintain minimum AA ratios (NRC, 1998). Large, 1,270 kg batches of the 1.15 and 1.53% Lys diets were manufactured then blended at ratios of 80:20, 60:40, 40:60, and 20:80, respectively, to achieve the intermediate Lys diets. The common diet fed from d 14 to 28 was corn-soybean meal-based and formulated to 1.26% SID Lys. The SID AA ratios relative to Lys were 61% Ile, 129% Leu, 58% Met and Cys, 63% Thr, 17.4% Trp, and 68% Val. Nutrients and SID AA digestibility coefficients used for all diet formulation were obtained from NRC (1998).

All experimental diets were in meal form and were prepared at the K-State Animal Science Feed Mill. A subsample of all experimental diets was collected and analyzed for dietary AA by Ajinomoto Heartland LLC (Chicago, IL) using HPLC as outlined by AOAC procedure 994.12 (AOAC, 2000). Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and G:F.

Experiments 2 to 4

In Exp. 2, 840 nursery pigs (PIC 337 × C22, initially 7.6 ± 0.13 kg) were used in a 14-d growth trial conducted at a commercial research nursery facility in Iowa. There were 24 pigs per pen and 7 replicate pens per treatment. Each pen (3.05 × 1.82 m) contained a stainless steel self-feeder and a single nipple waterer.

In Exp. 3, a total of 1,260 nursery pigs (PIC 327 × C14, initially 8.5 ± 0.14 kg) were used in a 14-d growth trial at a commercial research nursery facility in southern Minnesota. Each feeder was available to 2 adjacent pens, resulting in 42 pigs per feeder (21 pigs per pen) and 6 replicate feeders per treatment. Each pen (3.05 × 1.52 m) had access to a stainless steel self-feeder and one cup waterer.

In Exp. 4, a total of 770 nursery pigs (PIC TR4 × C22, initially 7.4 ± 0.07 kg) were used in a 14-d growth trial conducted at a commercial research nursery facility in Missouri. There were 22 pigs per pen and 7 replicate pens per treatment. Each pen (3.05 × 1.82 m) contained a stainless steel self-feeder and a cup waterer.

After weaning pigs were fed 544 g per pig of a common starter 1 diet (1.70% SID Lys), followed by a starter 2 diet (1.55% SID Lys) until d 10 after weaning. Treatment diets were fed starting on d 10 after weaning, which was considered d 0 of the experiment. Pens (Exp. 2 and 4) or pairs of pens sharing a common feeder (Exp. 3) were allotted to 1 of 5 dietary treatments in randomized complete block designs. The 5 SID Lys treatments were 1.22, 1.32, 1.42, 1.52, and 1.62%. Diets were corn-soybean meal-based and formulated to 3.45 Mcal of ME/kg. Soybean meal and lactose were kept constant between all treatments at 30% and 7% of the diet, respectively. Diets for Exp. 2 and 4 contained 5% select menhaden fish meal and 0.88% spray-dried blood cells (Table 2.2). In Exp. 3, select menhaden fish meal was added at 6.67% of the diet, and spray-dried blood cells were not included (Table 2.3). In all experiments, target SID Lys levels were achieved by increasing crystalline L-Lys·HCl. Other crystalline AA were added as needed to maintain minimum SID ratios relative to Lys of 60% Met and Cys, 65% Thr, 17% Trp, 55% Ile, and 69.3% Val. Nutrients and SID AA digestibility coefficients used for all diet formulation were obtained from NRC (1998). A subsample of all experimental diets was collected and analyzed for dietary AA by Ajinomoto Heartland LLC (Chicago, IL) using HPLC as outlined by AOAC procedure 994.12 (AOAC, 2000). Pigs and feeders were weighed on d 0, 7, 14 of the experiment to calculate ADG, ADFI, and G:F.

Statistical Analysis

Experimental data were analyzed for linear and quadratic effects of increasing SID Lys using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Pen was the experimental unit for data analysis in Exp. 1, 2, and 4. Feeder was the experimental unit for data analysis in Exp. 3. Significant effects for all experiments were declared at $P < 0.05$ and trends declared at $P < 0.10$. For combined data, break-point and quadratic broken-line analysis described by Robbins et al. (2006) was used to determine estimates of requirements. The breakpoint analysis was initially conducted separately for the experiment conducted in the university facility (Exp. 1) and compared with analysis from the commercial facilities (Exp. 2, 3, and 4). Because similar requirement estimates were found using university and commercial environments, all data was combined for final analysis as described by Kendall et al. (2008). When combining results from all experiments, data were expressed as a percentage of maximum ADG or G:F within each experiment.

RESULTS

Diet Analysis

Diet samples collected for Exp. 4 were lost between the time of collection and chemical analysis. Analyzed AA levels for Exp. 1 to 3 are shown in Tables 2.4 to 2.6, respectively. Analyzed concentrations are within acceptable limits for analytical variation according to AAFCO (2005). The AA analyses are in agreement with the design of the experiments, confirming that dietary Lys increased with increased SID Lys formulation.

Experiment 1

From d 0 to 14, ADG and ADFI increased (quadratic; $P < 0.002$) as SID Lys increased from 1.15 to 1.30% (Table 2.8), but there was no further increase at higher levels. Feed efficiency improved (linear; $P < 0.001$) with increasing SID Lys. Lysine intake per kg of gain increased (linear; $P < 0.001$) as SID Lys increased and was 16.6 and 16.7 g/kg at 1.30 and 1.38% SID Lys near the optimum levels for ADG and G:F, respectively. From d 14 to 28, when the common diet was fed, there was no difference in ADG, ADFI, or G:F, suggesting that the Lys level fed from d 0 to 14 had no affect on subsequent pig performance.

Average daily gain and ADFI increased (quadratic; $P < 0.05$) for the overall trial (d 0 to 28) as SID Lys increased. Again, the greatest ADG and ADFI were observed in pigs fed 1.30% SID Lys during phase 1. As SID Lys increased, there was a trend ($P < 0.10$) for increased G:F. Body weight increased (quadratic; $P < 0.05$), with pigs fed 1.30% SID Lys during phase 1 having the greatest BW on d 28. In this experiment, 1.30% SID Lys was adequate for optimal growth of 7- to 12-kg pigs.

Experiment 2

Increasing SID Lys during the first wk (d 0 to 7) increased ADG (linear, $P < 0.004$; quadratic, $P = 0.10$), ADFI (linear; $P < 0.04$) and G:F (quadratic; $P < 0.01$), with the pigs fed 1.42% SID Lys having the greatest performance (Table 2.9).

From d 7 to 14, ADG increased (quadratic; $P < 0.01$) as SID Lys increased. Increasing SID Lys increased (linear, $P < 0.01$) G:F, with pigs fed 1.42% SID Lys having the greatest G:F. There was no difference in ADFI from d 7 to 14 as Lys increased.

For the overall trial (d 0 to 14), increasing SID Lys increased (quadratic; $P < 0.01$) ADG and G:F with pigs fed 1.42% SID Lys having the greatest growth performance. As SID Lys increased, there was no difference in ADFI for the overall trial.

Lysine intake per kg of gain increased (quadratic, *P* < 0.005) as SID Lys increased and was 17.1 g/kg at 1.42% SID Lys near optimal levels for ADG and G:F.

Experiment 3

From d 0 to 7, increasing SID Lys increased (quadratic; *P* < 0.03) ADG and G:F through 1.52%, with no further improvement in growth performance for pigs fed 1.62% SID Lys (Table 2.10). There was also a trend (linear; *P* < 0.06) for increased ADFI for pigs fed increased SID Lys.

From d 7 to 14, increasing SID Lys increased (linear; *P* < 0.001) ADG and G:F with the greatest response from 1.22 to 1.32% and smaller improvements at higher levels. There was no difference in ADFI.

For the overall trial (d 0 to 14), increasing dietary Lys increased (quadratic; *P* < 0.02) ADG and G:F, with the greatest response to pigs fed 1.32% SID Lys and smaller improvements for pigs fed the higher Lys diets. There was no difference in ADFI with increasing SID Lys. Lysine intake per kg of gain increased (quadratic; *P* < 0.01) as SID Lys increased, was 18.0 at 1.32% SID Lys where the greatest response for ADG and G:F occurred, and increased to over 19 g/kg of gain where ADG was maximized.

Experiment 4

From d 0 to 7, there was no difference in ADG (Table 2.11); however ADFI decreased (linear; *P* < 0.02) and an G:F increased (linear; *P* < 0.001) as SID Lys increased (Table 2.11).

From d 7 to 14, ADG increased (quadratic; *P* < 0.01) as dietary Lys increased, with the pigs fed 1.42% SID Lys having the numerically greatest ADG. Similar to the previous period, ADFI decreased (linear; *P* < 0.001) and G:F increased (quadratic; *P* < 0.02) as SID Lys increased.

Overall from d 0 to 14, increasing SID Lys increased (quadratic; *P* < 0.05) ADG with the intermediate SID Lys diets (1.32 and 1.42%) having the highest gains. Also, ADFI decreased (linear; *P* < 0.001) and G:F increased (quadratic; *P* < 0.02) with increasing SID Lys. Lysine intake per kg of gain increased (quadratic; *P* < 0.05) as SID

Lys increased and was 16.8 and 17.1 g/kg at 1.32 and 1.42% SID Lys at the optimum levels for ADG, and 18.3 g/kg at 1.52% SID Lys at the optimum level for G:F.

Combined Results

Two slope breakpoint analysis of combined data of all experiments indicated that the breakpoint for ADG occurred at 1.30% SID Lys, whereas, the estimate using broken-quadratic analysis was slightly higher at 1.37% SID Lys (Figure 2.1A). When a separate analysis was conducted with only the data from the experiments conducted in commercial facilities (Exp. 2, 3, and 4), the estimate was similar at 1.31% and 1.42% for the two slope breakpoint and broken-quadratic analysis, respectively. Based on G:F for all experiments, the estimated requirement for SID Lys was 1.39% using broken-line analysis and 1.54% using broken-quadratic analysis (Figure 2.1B).

When expressing the SID Lys requirement in relationship to dietary energy, the requirement estimate for ADG was 3.86 g SID Lys/Mcal ME using the 2 slope breakpoint model and 4.19 g SID Lys/Mcal ME using the broken-quadratic model (Figure 2.2A). The requirement for G:F was higher than for ADG and was estimated as 4.18 g SID Lys/Mcal ME using a 2 straight-line, one breakpoint model and 4.92 g SID Lys/Mcal ME using a broken quadratic model (Figure 2.2B).

The Lys requirement was also expressed as g of SID Lys required per kg of daily gain (Figure 2.3). Broken line analysis for the combined data was inconclusive due to two outliers in the data set for ADG and one for G:F. The requirements for each trial were 16.5, 17.1, 17.5 to 19.9, and 16.7 to 17.5 g SID Lys/kg gain for Exp. 1, 2, 3, and 4, respectively. If the outliers were removed, the requirement estimates as g of SID Lys/kg gain were 16.7 and 17.1 g SID Lys/kg gain for ADG and G:F, respectively.

DISCUSSION

Since NRC (1998) publication, many experiments conducted with late nursery pigs have suggested that Lys requirements may be greater than previously estimated. The current requirement estimate by NRC (1998) for 10- to 25-kg pigs is 1.15% total Lys, or

1.01% SID Lys; however, Kendall et al. (2008) conducted 5 experiments with pigs from 11- to 27-kg and found that 1.30% SID Lys was required for optimal growth. Similarly, other recent studies in nursery pigs have estimated that the SID Lys requirement could be as high as 1.40%, also indicating that NRC (1998) recommendations may be too low (Lenehan et al., 2003; Hill et al., 2007) for today's modern lean genotype pig. Therefore, it is necessary to reevaluate the Lys requirement for nursery pigs in a lighter weight range.

In order to evaluate the SID Lys requirement of pigs from 7- to 14-kg, the present experiments were conducted using similar methods and design as Kendall et al. (2008). In the present studies as well as Kendall et al. (2008), a single-slope, broken-line analysis estimated a similar SID Lys requirement for gain of 1.30%. However, when comparing the results from Kendall et al. (2008) and our data, less of the variation in growth performance is explained by SID Lys in our trials than in those of Kendall et al. (2008). Although the primary difference was the weight range of the pigs, a number of other differences also existed that may help explain the variation. This includes varying locations, genetics, and minor changes in diet formulation in the current experiments, which were more consistent among trials by Kendall et al. (2008). Our experiments purposely involved four different nursery facilities and pig sources in order to encompass a broader range of environments in our SID Lys estimates. Despite the differences among experiments, similar requirements for ADG and G:F were found, allowing for the combination of data from all 4 experiments.

Statistical models are also an important consideration when evaluating nutritional requirements which may change depending on the method of analysis (Robbins et al., 1979; Kendall et al., 2008). When analyzing the combined results, two different models were used. A 2 slope breakpoint model is one of the most common models for determining nutritional requirements because it is a simple method that yields a break point estimate, standard error, and a description of the response (Robbins et al., 2006). The potential downside to this method is that it assumes the response leading up to the breakpoint remains linear. If the response becomes curvilinear before reaching the requirement, a broken-quadratic model may provide a more appropriate estimate (Robbins et al., 2006). For the combined data set, using a broken-quadratic model resulted in higher requirements and a greater difference of estimates between ADG and G:F than a 2 straight-line, one break point model.

Much of the earlier research reported the Lys requirement based on total dietary Lys, whereas investigating Lys requirements based on SID Lys can allow for more accurate estimates and may explain much of the variation among trials (Stein et al., 2005, 2007). We found that the total Lys required was at least 1.43% for ADG and 1.52% for G:F. Although there are experiments in agreement with the total dietary Lys required in the present trials (Gatel et al., 1992; Broekman et al., 1997), NRC (1998) reports experiments ranging in estimates from 1.10 to 1.40% total Lys. For the SID Lys requirement, our research found that at least 1.30% SID Lys was required for optimal ADG and 1.39% was required for optimal G:F in pigs from 7- to 14-kg was, based on a 2 straight-line, on break point model. These estimates are slightly lower than those reported by Dean et al. (2007), who found that the SID Lys requirement for optimal ADG is between 1.40 and 1.43% in pigs from 6- to 12-kg, by using broken-line analysis. However, when calculated as a Lys-to-calorie ratio, this can be expressed as 4.1 g SID Lys/Mcal ME, which is similar to estimates in the current experiments of 3.9 to 4.2 g SID Lys/Mcal ME. Also in agreement, Schneider et al. (2010) found that Lys-to-calorie ratio requirement may differ between genotypes in nursery pigs, but reported the requirement of a similar genetic source as used in our trials to be 3.9 to 4.2 g SID Lys/Mcal ME. When expressed as a function of SID Lys required per kilogram of daily gain, our experiments ranged in requirements from 16.5 to 19.9 g SID Lys/kg gain with three of the experiments having estimated requirements of 16.5 to 17 g/kg. Calculating the requirement reported by Dean et al. (2007) relative to daily gain provides an estimate of 18.9 g SID Lys/kg gain for pigs from 6 to 12 kg. Similarly, Kendall et al. (2008) found the requirement for heavier nursery pigs to be 19.0 g SID Lys/kg gain. Combined, these experiments indicate that providing 19.0 g of SID Lys/kg gain will meet or exceed the requirement of pigs from 6 to 27 kg and that the requirement may be as low as 16.5 to 17 g of SID Lys/kg gain for 6 to 12 kg pigs.

In summary, the current experiments agree with recent nursery pig research with heavier pigs in indicating that NRC (1998) Lys recommendations appear to be too low. For pigs from 7- to 14-kg, our data found that the SID Lys requirement for optimal growth was at least 1.30% for ADG and 1.39% for G:F by using 2 straight-line, one break point analysis. Using broken quadratic models provided higher estimates, which were more variable and ranged from 1.37 to 1.54% SID Lys. When calculated as SID Lys:ME, the requirement appears to be at least 3.86 g/Mcal ME.

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FIGURES AND TABLES

Table 2.1 Composition of diets, Exp. 1 (as-fed-basis)[1]

Item	Phase 1 standardized ileal digestible lysine, %[2]						Common
	1.15	1.23	1.30	1.38	1.45	1.53	Phase 2[3]
Ingredient, %							
Corn	61.12	58.85	56.58	54.31	52.04	49.77	65.05
Soybean meal (46.5% CP)	20.80	23.00	25.21	27.41	29.62	31.83	30.73
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	10.00	---
Select menhaden fish meal	4.50	4.50	4.50	4.50	4.50	4.50	---
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	---
Monocalcium phosphate (21% P)	0.55	0.53	0.51	0.49	0.47	0.45	1.08
Limestone	0.55	0.55	0.55	0.55	0.55	0.55	0.95
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.35
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25	---
Trace mineral premix[4]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix[5]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lys·HCl	0.225	0.250	0.275	0.300	0.325	0.350	0.360
DL-Met	0.080	0.102	0.124	0.146	0.168	0.190	0.130
L-Thr	0.100	0.118	0.136	0.154	0.172	0.190	0.130
L-Trp	0.040	0.043	0.046	0.049	0.052	0.055	---
L-Val	0.005	0.021	0.037	0.053	0.069	0.085	---
Phytase[6]	0.085	0.085	0.085	0.085	0.085	0.085	0.165
TOTAL	100	100	100	100	100	100	100
Calculated analysis							
Standardized ileal digestible (SID) amino acids, %							
Lys	1.15	1.23	1.30	1.38	1.45	1.53	1.26
Ile:Lys	62	61	60	60	59	59	61
Leu:Lys	132	128	125	122	119	116	129
Met:Lys	34	34	35	35	36	36	33
Met & Cys:Lys	58	58	58	58	58	58	58
Thr:Lys	64	64	64	64	64	64	63
Trp:Lys	20	20	20	20	20	20	17.4
Val:Lys	70	70	70	70	70	70	68
Total Lys, %	1.27	1.35	1.43	1.51	1.59	1.67	1.39
ME, Mcal/kg	3.37	3.37	3.37	3.37	3.37	3.37	3.31
SID Lys:ME, g/Mcal	3.41	3.64	3.86	4.08	4.30	4.52	3.80
CP, %	19.3	20.2	21.1	22.0	22.9	23.8	20.8
Ca, %	0.71	0.71	0.72	0.72	0.72	0.72	0.69
P, %	0.64	0.64	0.65	0.65	0.66	0.66	0.62
Available P, %	0.47	0.47	0.47	0.47	0.47	0.47	0.42

[1]A total of 294 nursery pigs (PIC TR4 × 1050, 6.76 ± 0.08 kg BW) were used in a 28-d growth trial to evaluate the effects of SID Lys level on growth performance in a university research nursery facility. There were 7 pigs per pen and 7 pens per treatment.

[2]Treatment diets were fed from d 0 to 14.

[3]Common diet was fed from d 14 to 28.

[4]Trace mineral premix provided per kg of complete feed: 16.5 mg of Cu from $CuSO_4 \cdot 5H^2 0$, 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$, 165 mg of Fe as $FeSO_4H_2O$, 39.7 mg of Mn as $MnSO_4 \cdot H20$, 0.30 mg of Se as Na_2SeO_3, and 165 mg of Zn as $ZnSO_4$.

[5]Vitamin premix provided per kg of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B_{12}, 50.0 mg of niacin, 27.6 mg of pantothenic acid, and 8.3 mg of riboflavin.

[6]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 509 FTU/kg, with a release of 0.10% available P.

Table 2.2 Composition of diets, Exp. 2[1] and 4[2] (as-fed-basis)

	Standardized ileal digestible lysine, %				
Item	1.22	1.32	1.42	1.52	1.62
Ingredient, %					
Corn	51.29	51.04	50.78	50.42	50.02
Soybean meal (48% CP)	30.00	30.00	30.00	30.00	30.00
Lactose[3]	7.00	7.00	7.00	7.00	7.00
Select menhaden fish meal	5.00	5.00	5.00	5.00	5.00
Spray-dried blood cells	0.88	0.88	0.88	0.88	0.88
Choice white grease	3.00	3.00	3.00	3.00	3.00
Dicalcium phosphate (18.5%)	1.15	1.15	1.15	1.15	1.15
Limestone	0.37	0.37	0.37	0.37	0.37
Salt	0.40	0.40	0.40	0.40	0.40
Tri-basic copper chloride	0.10	0.10	0.10	0.10	0.10
Trace mineral premix[4]	0.15	0.15	0.15	0.15	0.15
Vitamin premix[5]	0.25	0.25	0.25	0.25	0.25
L-Lys·HCl	0.00	0.13	0.26	0.38	0.51
DL-Met	0.09	0.15	0.21	0.27	0.34
L-Thr	0.07	0.14	0.21	0.27	0.34
L-Trp	---	---	---	0.02	0.04
L-Ile	---	---	---	0.01	0.07
L-Val	---	---	---	0.07	0.14
Medication[6]	0.13	0.13	0.13	0.13	0.13
TOTAL	100	100	100	100	100
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lys	1.22	1.32	1.42	1.52	1.62
Ile:Lys	67.8	62.6	58.1	55.0	55.0
Met & Cys:Lys	60.0	60.0	60.0	60.0	60.0
Thr:Lys	65.0	65.0	65.0	65.0	65.0
Trp:Lys	19.8	18.3	17.0	17.0	17.0
Val:Lys	80.8	74.6	69.3	69.3	69.3
Total Lys, %	1.35	1.46	1.56	1.65	1.75
ME, Mcal/kg	3.45	3.45	3.45	3.45	3.45
SID Lys:ME, g/Mcal	3.54	3.83	4.12	4.41	4.70
CP, %	22.56	22.75	22.94	23.12	23.31
Ca, %	0.80	0.80	0.80	0.80	0.80
Available P, %	0.40	0.40	0.40	0.40	0.40

[1]In Exp. 2, 840 nursery pigs (PIC 337 × C22, initially 7.6 ± 0.13 kg) were used in a 14-d growth trial conducted at a commercial research nursery facility in Iowa. There were 24 pigs per pen and 7 replicate pens per treatment.

[2]In Exp. 4, 770 nursery pigs (PIC TR4 × C22, initially 7.4 ± 0.07 kg) were used in a 14-d growth trial conducted at a commercial research nursery facility in Missouri. There were 22 pigs per pen and 7 replicate pens per treatment.

[3]Dairy Lac 80 (80% lactose equivalence) provided by International Ingredients, Inc., St. Louis, MO.

[4]Trace mineral premix provided per kg of diet: 16.5 mg of Cu from $CuSO_4$, 0.3 mg of I as $Ca(IO_3)_2$, 165.3 mg of Fe from $FeSO_4$, 33 mg of Mn from $MnSO_4$ and MnO, 0.29 mg of Se from

Na_2SeO_3, 165.3 mg of Zn from $ZnSO_4$.

[5]Vitamin premix provided per kg of diet: 11,000 IU of vitamin A, 1,100 IU of vitamin D, 22 IU of vitamin E, 3.99 mg of vitamin K as menadione, 0.03 mg of vitamin B_{12}, 3 mg of thiamin, 33 mg of niacin, 28.05 mg of pantothenic acid, 8.25 mg of riboflavin, 0.5 mg of biotin, and 1.5 mg of folic acid.

[6]Mecadox (Phibro Animal Health, Ridgefield Park, NJ) was supplemented at 55 mg/kg.

Table 2.3 Composition of diets, Exp. 3 (as-fed-basis)[1]

	Standardized ileal digestible lysine, %				
Item	1.22	1.32	1.42	1.52	1.62
Ingredient, %					
Corn	50.39	50.13	49.87	49.53	49.13
Soybean meal (48% CP)	30.00	30.00	30.00	30.00	30.00
Lactose	7.00	7.00	7.00	7.00	7.00
Select menhaden fish meal	6.67	6.67	6.67	6.67	6.67
Choice white grease	3.00	3.00	3.00	3.00	3.00
Dicalcium phosphate (18.5%)	0.88	0.88	0.88	0.88	0.88
Limestone	0.33	0.33	0.33	0.33	0.33
Salt	0.40	0.40	0.40	0.40	0.40
Zinc Oxide	0.25	0.25	0.25	0.25	0.25
Vitamin and trace mineral premix[2]	0.30	0.30	0.30	0.30	0.30
L-Lys·HCl	0.00	0.13	0.26	0.38	0.51
DL-Met	0.05	0.12	0.18	0.24	0.30
L-Thr	0.04	0.10	0.17	0.24	0.30
L-Trp	---	---	---	0.02	0.04
L-Ile	---	---	---	---	0.06
L-Val	---	---	---	0.07	0.14
Medication[3]	0.70	0.70	0.70	0.70	0.70
TOTAL	100	100	100	100	100
Calculated analysis					
Standardized ileal digestible (SID) amino acids, %					
Lys	1.22	1.32	1.42	1.52	1.62
Ile:Lys	70.5	65.1	60.4	56.4	56.4
Met & Cys:Lys	60.0	60.0	60.0	60.0	60.0
Thr:Lys	65.0	65.0	65.0	65.0	65.0
Trp:Lys	19.7	18.2	16.9	16.9	16.9
Val:Lys	78.4	72.4	67.2	67.2	67.2
Total Lys, %	1.36	1.47	1.56	1.65	1.75
ME, kcal/kg	3.45	3.45	3.45	3.45	3.45
SID Lys:ME, g/Mcal	3.54	3.83	4.12	4.41	4.70
CP, %	22.63	22.81	23.00	23.25	23.53
Ca, %	0.80	0.80	0.80	0.80	0.80
Available P, %	0.40	0.40	0.40	0.40	0.40

[1]A total of 1,260 nursery pigs (PIC 327 × C14, initially 8.45 ± 0.11 kg BW) were used in a 14-d growth trial to evaluate the effects of SID lysine level on growth performance in a commercial research nursery facility in southern Minnesota. There were 42 pigs per feeder (21 pigs per pen) and 6 replicate feeders per treatment.

[2]Vitamin and trace mineral premix provided per kg of diet: 12 IU of vitamin A, 1,801 IU of vitamin D, 60.1 IU of vitamin E, 4.4 mg of vitamin K, 0.03 mg of vitamin B_{12}, 50.0 mg of niacin, 28.6 mg of pantothenic acid, 8.3 mg of riboflavin, 0.33 mg of biotin, 3.6 mg of folic acid, 5.0 mg of pyridoxine, 11.2 mg of Cu from $CuSO_4$, 0.66 mg of I as $Ca(IO_3)_2$, 151 mg of Fe from $FeSO_4$, 55.6 mg of Mn from $MnSO_4$ and MnO, 0.30 mg of Se from Na_2SeO_3, 198 mg of Zn from $ZnSO_4$, and 300 FTU/kg of phytase.

Table 2.4 Analyzed nutrient composition of diets, Exp. 1 (as-fed-basis)

	Standardized ileal digestible Lys, %					
Item, %	1.15	1.23	1.30	1.38	1.45	1.53
Lys	1.20[1] (1.27)[2]	1.24 (1.35)	1.34 (1.43)	1.39 (1.51)	1.46 (1.59)	1.50 (1.67)
Ile	0.78 (0.80)	0.79 (0.84)	0.84 (0.88)	0.89 (0.93)	0.92 (0.96)	0.95 (1.01)
Met	0.41 (0.42)	0.42 (0.45)	0.46 (0.48)	0.48 (0.52)	0.47 (0.55)	0.51 (0.58)
Met + Cys	0.68 (0.74)	0.70 (0.79)	0.75 (0.83)	0.77 (0.88)	0.79 (0.92)	0.82 (0.97)
Thr	0.83 (0.85)	0.85 (0.91)	0.90 (0.96)	0.95 (1.01)	0.97 (1.06)	1.01 (1.12)
Trp	0.26 (0.26)	0.26 (0.28)	0.28 (0.29)	0.30 (0.31)	0.32 (0.32)	0.32 (0.34)
Val	0.86 (0.91)	0.90 (0.97)	0.96 (1.03)	1.00 (1.09)	1.07 (1.14)	1.09 (1.20)

[1]A representative sample of each diet was collected and analyzed for amino acid composition.
[2]Values in parentheses indicate formulated values.

Table 2.5 Analyzed nutrient composition of diets, Exp. 2 (as-fed-basis)

	Standardized ileal digestible Lys, %				
Item, %	1.22	1.32	1.42	1.52	1.62
Lys	1.40[1] (1.35)[2]	1.52 (1.45)	1.60 (1.55)	1.72 (1.65)	1.84 (1.75)
Ile	0.95 (0.92)	0.96 (0.92)	0.98 (0.92)	1.01 (0.93)	1.04 (0.99)
Met	0.40 (0.46)	0.39 (0.52)	0.42 (0.58)	0.40 (0.64)	0.40 (0.70)
Met + Cys	0.89 (0.81)	0.94 (0.87)	1.03 (0.93)	1.03 (0.99)	1.15 (1.05)
Thr	0.83 (0.91)	0.85 (0.97)	0.90 (1.04)	0.95 (1.10)	0.97 (1.17)
Trp	0.28 (0.26)	0.29 (0.26)	0.26 (0.27)	0.26 (0.29)	0.31 (0.30)
Val	1.14 (1.04)	1.17 (1.03)	1.17 (1.10)	1.26 (1.17)	1.33 (1.24)

[1]A representative sample of each diet was collected and analyzed for amino acid composition.

[2]Values in parentheses indicate formulated values.

Table 2.6 Analyzed nutrient composition of diets, Exp. 3 (as-fed-basis)

	Standardized ileal digestible Lys, %				
Item, %	1.22	1.32	1.42	1.52	1.62
Lys	1.25[2] (1.36)[3]	1.36 (1.47)	1.47 (1.56)	1.54 (1.65)	1.65 (1.75)
Ile	0.92 (0.96)	0.93 (0.96)	0.93 (0.96)	0.93 (0.95)	0.95 (1.01)
Met	0.45 (0.46)	0.51 (0.52)	0.56 (0.58)	0.60 (0.64)	0.72 (0.70)
Met + Cys	0.79 (0.81)	0.85 (0.87)	0.90 (0.93)	0.94 (0.99)	1.04 (1.05)
Thr	0.93 (0.91)	0.98 (0.97)	1.05 (1.04)	1.08 (1.10)	1.16 (1.17)
Trp	0.26 (0.26)	0.26 (0.26)	0.26 (0.27)	0.27 (0.29)	0.28 (0.30)
Val	1.04 (1.01)	1.05 (1.00)	1.04 (1.00)	1.11 (1.09)	1.16 (1.16)

[1]A representative sample of each diet was collected and analyzed for amino acid composition.

[2]Values in parentheses indicate formulated values.

Table 2.7 Evaluation of standardized ileal digestible (SID) lysine on growth performance of nursery pigs, Exp. 1[1]

	SID lysine, %[2]							Probability, *P* <	
	1.15	1.23	1.30	1.38	1.45	1.53	SEM	Linear	Quadratic
d 0 to 14									
ADG, g	290	306	342	328	330	284	13.43	0.80	0.001
ADFI, g	388	394	435	396	398	336	16.36	0.04	0.002
G:F	0.743	0.775	0.787	0.830	0.830	0.846	0.015	<0.001	0.36
Lys, g/kg gain	15.49	15.90	16.56	16.67	17.54	18.10	0.318	<0.001	0.57
d 14 to 28									
ADG, g	474	482	473	477	455	472	16.01	0.54	0.96
ADFI, g	799	812	827	798	805	793	18.56	0.61	0.36
G:F	0.593	0.594	0.570	0.598	0.567	0.595	0.015	0.75	0.44
d 0 to 28									
ADG, g	382	393	407	403	392	378	12.06	0.81	0.05
ADFI, g	594	602	630	597	602	564	15.27	0.17	0.03
G:F	0.643	0.653	0.645	0.675	0.653	0.669	0.011	0.10	0.81
BW, kg									
d 0	6.76	6.76	6.75	6.76	6.77	6.74	0.083	0.96	0.90
d 14	10.81	11.04	11.53	11.36	11.38	10.75	0.216	0.76	0.004
d 28	17.44	17.73	18.22	18.03	17.76	17.36	0.343	0.86	0.05

[1] A total of 294 nursery pigs (initially 6.76 ± 0.08 kg BW) were used in a 28-d growth trial to evaluate the effects of SID lysine level on growth performance. There were 7 pigs per pen and 7 pens per treatment. Pigs were weaned at approximately 21 d of age, fed a common diet for 3 d, and then started on test.

[2] Treatment diets were fed from d 0 to 14 and a common diet fed from d 14 to 28.

Table 2.8 Evaluation of standardized ileal digestible (SID) lysine on growth performance of nursery pigs, Exp. 2[1]

	SID lysine, %						Probability, *P* <	
	1.22	1.32	1.42	1.52	1.62	SEM	Linear	Quadratic
d 0 to 7								
ADG, g	329	334	393	358	373	11.33	0.004	0.10
ADFI, g	407	385	429	426	419	9.39	0.04	0.64
G:F	0.807	0.865	0.915	0.838	0.890	0.013	0.003	0.01
d 7 to 14								
ADG, g	490	509	529	536	509	9.92	0.05	0.01
ADFI, g	677	665	680	702	653	15.60	0.84	0.28
G:F	0.725	0.767	0.780	0.766	0.780	0.013	0.01	0.11
d 0 to 14								
ADG, g	410	421	461	447	441	8.70	0.003	0.01
ADFI, g	542	524	554	564	536	11.17	0.44	0.34
G:F	0.756	0.803	0.832	0.793	0.823	0.008	<0.001	0.001
Lys, g/kg gain	16.15	16.44	17.08	19.18	19.69	0.170	<0.001	0.005
BW, kg								
d 0	7.56	7.56	7.57	7.57	7.57	0.135	0.94	0.98
d 7	9.86	9.89	10.32	10.07	10.18	0.182	0.17	0.45
d 14	13.29	13.55	14.02	13.83	13.80	0.208	0.06	0.12

[1] A total of 840 nursery pigs (initially 7.57 ± 0.14 kg BW) were used in a 14-d growth trial to evaluate the effects of SID lysine level on growth performance in a commercial nursery research facility in Iowa. Data represents the means of 7 replicate pens per treatment with 24 pigs per pen.

Table 2.9 Evaluation of standardized ileal digestible (SID) lysine on growth performance of nursery pigs, Exp. 3[1]

	SID lysine, %						Probability, $P <$	
	1.22	1.32	1.42	1.52	1.62	SEM	Linear	Quadratic
d 0 to 7								
ADG, g	244	282	291	313	308	8.71	<0.001	0.03
ADFI, g	391	404	399	417	409	8.03	0.06	0.57
G:F	0.622	0.697	0.731	0.750	0.751	0.015	<0.001	0.01
d 7 to 14								
ADG, g	454	491	504	505	514	11.67	0.001	0.13
ADFI, g	643	645	656	653	650	9.10	0.47	0.52
G:F	0.705	0.761	0.768	0.774	0.790	0.012	<0.001	0.09
d 0 to 14								
ADG, g	349	386	397	409	410	7.83	<0.001	0.02
ADFI, g	517	524	527	535	529	7.50	0.16	0.50
G:F	0.674	0.737	0.754	0.765	0.775	0.010	<0.001	0.01
Lys, g/kg gain	18.13	17.96	18.86	19.91	20.89	0.239	<0.001	0.01
BW, kg								
d 0	8.47	8.44	8.45	8.46	8.45	0.112	0.99	0.94
d 7	10.17	10.41	10.48	10.66	10.60	0.136	0.02	0.35
d 14	13.35	13.86	14.03	14.20	14.22	0.165	0.001	0.13

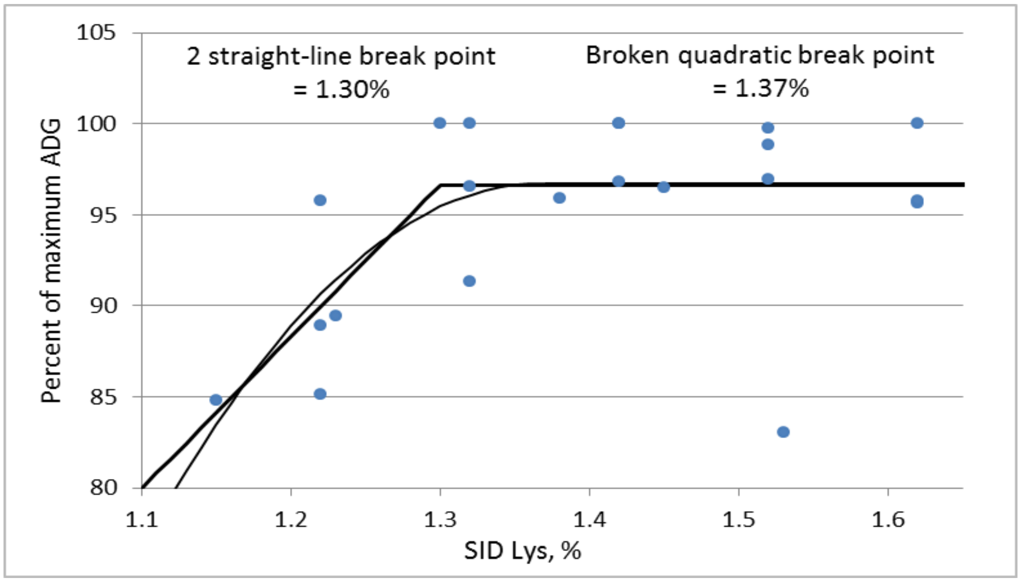
[1] A total of 1,260 nursery pigs (initially 8.45 ± 0.11 kg BW) were used in a 14-d growth trial to evaluate the effects of SID lysine level on growth performance in a commercial research nursery facility in Minnesota. Data represents the means of 6 replicate feeders per treatment with 42 pigs per feeder.

Table 2.10 Evaluation of standardized ileal digestible (SID) lysine on growth performance of nursery pigs, Exp. 4[1]

	SID lysine, %						Probability, $P <$	
	1.22	1.32	1.42	1.52	1.62	SEM	Linear	Quadratic
d 0 to 7								
ADG, g	355	363	355	354	350	15.68	0.71	0.77
ADFI, g	468	454	436	422	422	16.01	0.02	0.13
G:F	0.761	0.795	0.810	0.837	0.827	0.015	<0.001	0.29
d 7 to 14								
ADG, g	463	491	500	488	468	16.21	0.88	0.01
ADFI, g	625	621	622	581	567	16.89	0.001	0.13
G:F	0.743	0.792	0.805	0.838	0.826	0.010	<0.001	0.02
d 0 to 14								
ADG, g	409	427	427	422	409	15.58	0.74	0.05
ADFI, g	545	541	526	503	494	16.74	0.001	0.61
G:F	0.752	0.790	0.809	0.837	0.826	0.009	<0.001	0.02
Lys, g/kg gain	16.26	16.81	17.71	18.28	19.75	0.195	<0.001	0.05
BW, kg								
d 0	7.35	7.32	7.40	7.44	7.39	0.141	0.50	0.79
d 7	9.84	9.89	9.86	9.93	9.85	0.198	0.95	0.86
d 14	13.10	13.30	13.37	13.30	13.12	0.250	0.98	0.17

[1] A total of 770 nursery pigs (initially 7.38 ± 0.14 kg BW) were used in a 14-d growth trial to evaluate the effects of SID lysine level on growth performance in a commercial research nursery facility in Missouri. Data represents the means of 7 replicate pens per treatment with 22 pigs per pen.

A



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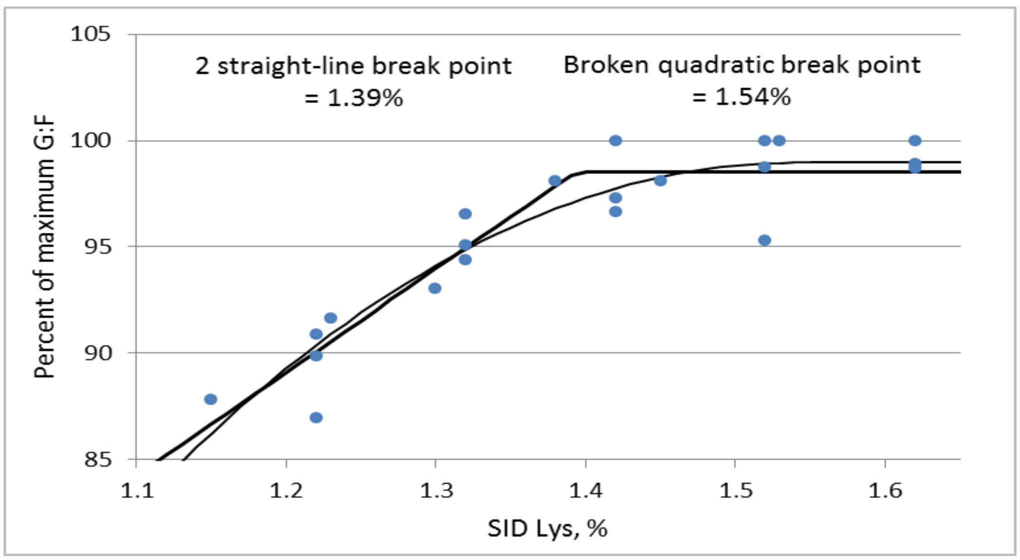
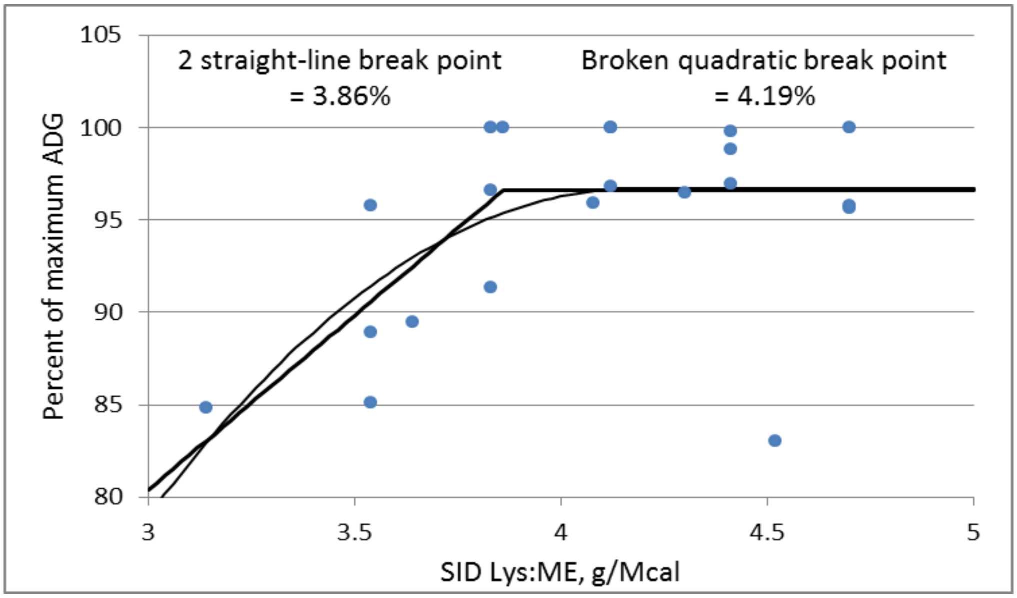


Figure 2.1

A) Fitted 2 straight-line, one break point and broken quadratic plot of percentage of maximum ADG expressed as a function of standardized ileal diestible (SID) Lys in 7- to 14-kg pigs. Data points represent treatment means from 4 experiments totalling 3,164 pigs. The 2 straight-line, one break point model yielded a SID Lys requirement of 1.30% (r^2 = 0.42) and the broken quadratic model yielded a SID Lys requirement of 1.37% (r^2 = 0.40). B) Fitted 2 straight-line, one break point and broken quadratic plot of percentage of maximum G:F expressed as a function of SID Lys in 7- to 14-kg pigs. Data points represent treatment means from 4 experiments totalling 3,164 pigs. The 2 straight-line, one break point model yielded a SID Lys requirement of 1.39% (r^2 = 0.88) and the broken quadratic model yielded a SID Lys requirement of 1.54% (r^2 = 0.87).

A



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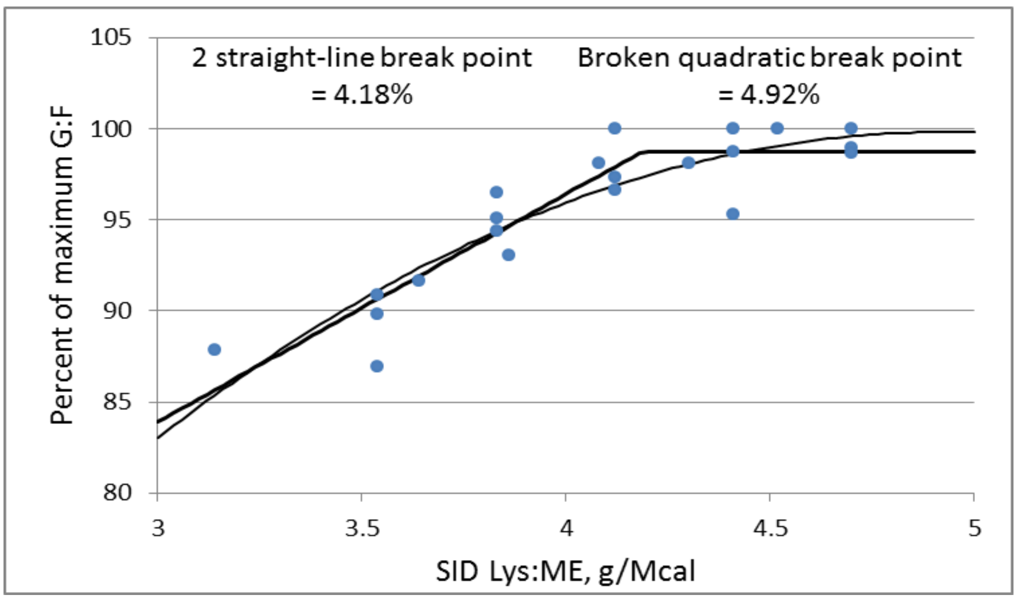

Figure 2.2
A) Fitted 2 straight-line, one break point and broken quadratic plot of percentage of maximum ADG expressed as a function of standardized ileal digestible (SID) Lys:ME in 7- to 14-kg pigs. Data points represent treatment means from 4 experiments totalling 3,164 pigs. The 2 straight-line, one break point model yielded a SID Lys:ME requirement of 3.86 g/Mcal (r^2 = 0.31) and the broken quadratic model yielded a SID Lys requirement of 4.19 g/Mcal (r^2 = 0.47). B) Fitted 2 straight-line, one break point and broken quadratic plot of percentage of maximum G:F expressed as a function of SID Lys:ME in 7- to 14-kg pigs. Data points represent treatment means from 4 experiments totalling 3,164 pigs. The 2 straight-line, one break point model yielded a SID Lys:ME requirement of 4.18 g/Mcal (r^2 = 0.85) and the broken quadratic model yielded a SID Lys:ME requirement of 4.92 g/Mcal (r^2 = 0.82).

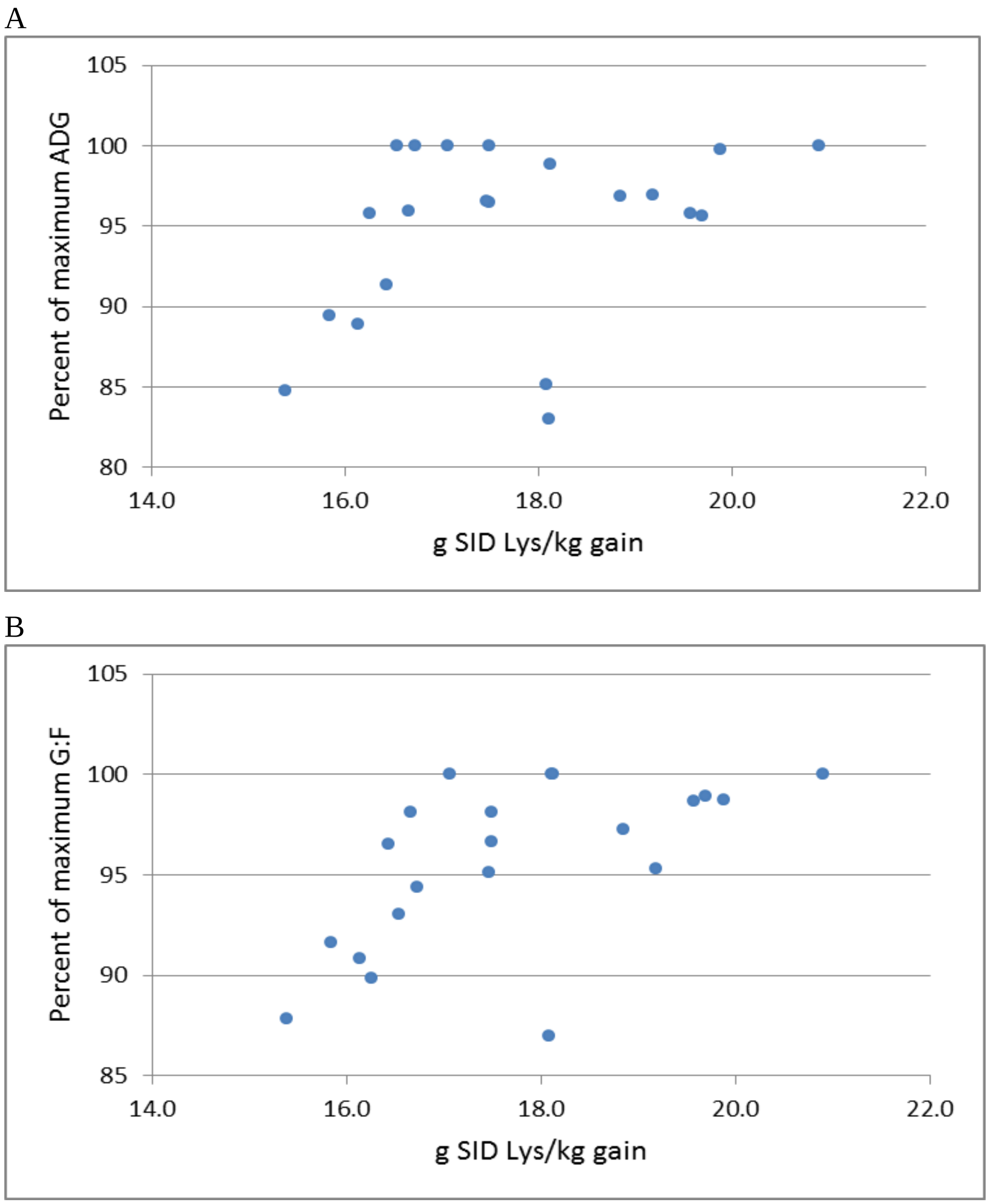

Figure 2.3
A) Plot of percentage of maximum ADG expressed as a function of standardized ileal digestible (SID) Lys required per kg of daily gain in 7- to 14-kg pigs. Data points represent treatment means from 4 experiments totalling 3,164 pigs. B) Plot of percentage of maximum G:F expressed as a function of SID Lys required per kg of daily gain in 7- to 14-kg pigs. Data points represent treatment means from 4 experiments totalling 3,164 pigs.

Chapter 3 - Evaluation of SID valine:lysine, total lysine:CP, and replacing specialty protein sources with crystalline amino acids on growth performance of nursery pigs from 7- to 12- kg

ABSTRACT

Five experiments were conducted to evaluate the effect of replacing specialty protein sources with crystalline AA for 7- to 12-kg pigs. In all experiments, pigs (PIC TR4 × 1050) were fed a common diet for 3 d postweaning, then treatment diets were fed from d 0 to 14. Treatment diets were corn-soybean meal-based and were formulated to 1.30% standardized ileal digestible (SID) Lys. Experiment 1 evaluated the effects of replacing dietary fish meal with crystalline AA. For the 6 dietary treatments, crystalline Lys, Met, Thr, Trp, Ile, Val, Gln, and Gly all increased to maintain minimum AA ratios as fish meal decreased. There was no difference in ADG, ADFI, or G:F as fish meal decreased and crystalline AA increased, validating a low-CP AA-fortified diet that could be used in subsequent experiments. Experiment 2 determined the effect of deleting crystalline AA from a low-CP, AA-fortified diet. The 6 treatments were (1) a positive control (PC), (2) PC with L-Ile deleted, (3) PC with L-Trp deleted, (4) PC with L-Val deleted, (5) PC with L-Gln and L-Gly deleted, and (6) PC with L-Ile, L-Trp, L-Val, L-Gln, and L-Gly deleted from diet (NC). Amino acid-to-Lys ratios of the positive and negative control diets were: Ile (60 vs 52%), Trp (20 vs 15%), and Val (70 vs 57%), with total Lys:CP ratios of 6.8 and 7.5%, respectively. Pigs fed the PC or Ile deleted diet had improved ADG and ADFI compared with pigs fed diets with L-Trp or L-Val deleted or the NC, suggesting minimum SID Trp- and Val:Lys requirements are greater than 15 and 57%, respectively. Pigs fed the diet with no L-Gln and L-Gly had intermediate ADG and ADFI. Experiment 3 evaluated the effects of total Lys:CP on growth performance. The total Lys:CP ratios tested were 6.79, 6.92, 7.06, 7.20, 7.35, and 7.51%. Lysine concentration was 1.30% SID and fish meal was adjusted as a source of non-essential N to achieve the target Lys:CP. Both ADG and G:F tended to increase (quadratic, $P < 0.09$) as total Lys:CP increased from 6.79 to 7.35% then returned to control values in the pigs fed the highest Lys:CP. Experiment 4 evaluated the effects of increasing SID Val:Lys (57.4, 59.9, 62.3, 64.7, 67.2, 69.6% of Lys) on growth performance. Average daily gain and ADFI increased (quadratic, $P < 0.01$) and G:F improved (linear, $P < 0.02$) as Val:Lys increased from 57.4 to 64.7% with little improvement observed thereafter. Experiment 5 was a 2 × 3 factorial with main effects of either low or high levels of crystalline AA and three specialty protein sources (fish meal, meat and bone meal, or poultry meal). Low and high crystalline AA diets contained 4.5 or 1% fish meal, 6 or 1.2% meat and bone meal, and 6 or 1% poultry meal, respectively. There were no AA × protein source interactions. From d 0 to 14, there were no differences among protein sources for ADG, ADFI, or G:F. Increasing crystalline AA improved ($P < 0.04$) ADG due to numerical increases in ADFI and G:F. In conclusion, crystalline AA can replace specialty protein sources, when balanced for SID AA ratios of Met and Cys:Lys (58%), Thr:Lys (62%), Trp:Lys (16.5%), Val:Lys (65%), and Ile:Lys (52%) and total Lys:CP (≤ 7.35%).

Key Words: crystalline amino acids, non-essential amino acid, pig, protein source, valine

INTRODUCTION

Several experiments have been conducted to evaluate replacing specialty protein with crystalline AA in the diet for nursery pigs. Low-protein AA fortified diets have resulted in performance similar to that of the specialty protein sources in several trials (Frantz et al., 2005; Ratliff et al., 2005b; Bradley et al., 2008), but not in others (Kats et al. 1994; Davis et al. 1997; de Rodas et al. 1997). Much of the variation among experiments can be explained by the increased use of standardized ileal digestible (SID) ratios in diet formulation. Standardized ileal digestible AA estimates for most common feed ingredients are available, which allows for more accurate formulation to meet the AA requirements of the pigs (Stein et al., 2005, 2007). Decreases in performance from pigs fed low-CP AA fortified diets may also be a result of deficiencies in nonessential N, variation in lactose levels, or diets only being formulated to the second or third limiting AA (Kats et al., 1994; de Rodas et al., 1997; Chung et al., 1999).

The objective of the following series of experiments was to evaluate the effect of replacing specialty protein sources with crystalline AA on growth performance of nursery pigs from 7- to 12-kg. In order to accomplish the overall objective, the sub-objectives were to: 1) establish a low-CP, AA-fortified diet that could be used to replace specialty protein (fish meal) for subsequent experiments, 2) determine which AA were required in the low-CP, AA fortified diet for optimal growth, 3) evaluate the maximum total Lys:CP required for growth, 4) determine the minimum SID Val:Lys requirement, and 5) validate crystalline AA as a replacement for fish meal, meat and bone meal, and poultry meal.

MATERIALS AND METHODS

All experimental procedures and animal care were approved by the Kansas State University Institutional Animal Care and Use Committee.

General

Similar protocols were used in all 5 experiments. Pigs (PIC TR4 × 1050, Hendersonville, TN) were weaned at 19.5 ± 1.4 d of age and fed a common pelleted starter diet for 3 d. At weaning, pigs were allotted to pens by initial BW to achieve the same average weight for all pens. Each pen (1.22 × 1.52 m) contained a 4-hole, dry self-feeder and a nipple waterer to provide ad libitum access to feed and water. On d 3 after weaning, pens were allotted randomly to 1 of 6 dietary treatments. Thus, d 3 after weaning was d 0 of the experiment. All experiments were conducted at the Kansas State University Swine Teaching and Research Center.

A 2-phase diet series was used, with treatment diets fed from d 0 to 14 and a common diet fed from d 14 to 28. Treatment diets were corn-soybean meal-based, contained 10% dried whey and 1% soy oil. Diets were formulated to a predetermined SID Lys level of 1.30% (Nemechek et al., 2011). The subsequent common diet for all the trials was a corn-soybean meal-based diet with no specialty protein sources, formulated to 1.26% SID Lys. Nutrients and SID AA digestibility coefficients used for all diet formulation were obtained from NRC (1998). All experimental diets were in meal form and were prepared at the Kansas State University Animal Science Feed Mill. A subsample of all experimental diets was collected and analyzed for dietary AA by Ajinomoto Heartland LLC (Chicago, IL) using HPLC as outlined by AOAC procedure 994.12 (AOAC, 2000). Pigs and feeders were weighed on d 0, 7, 14, 21, and 28 to calculate ADG, ADFI, and G:F.

Experiment 1

A total of 282 nursery pigs (initially 7.30 ± 0.08 kg BW) were used in a 28-d trial to evaluate the effects of replacing dietary fish meal with crystalline AA on growth performance. Each treatment had 5 replications with 7 pigs per pen and 2 replications with 6 pigs per pen. For the 6 dietary treatments, crystalline L-Lys, DL-Met, L-Thr, L-Trp, L-Ile, and L-Val were added to maintain minimum AA ratios at the expense of fish meal (Table 3.1). Dietary fish meal levels were 4.50, 3.60, 2.70, 1.80, 0.90, and 0.00%. Salt increased slightly with decreasing fish meal in order to maintain equal dietary Na among treatments. Also, increasing amounts of L-Gln and L-Gly were used in diets containing 3.60% or less fish meal to maintain a total Lys:CP ratio of no more than 7:1%. Large, 1,270 kg, batches of 4.50 and 0.00% fish meal diets were first manufactured then blended at ratios of 80:20, 60:40, 40:60, and 20:80, respectively, to achieve the intermediate diets.

Experiment 2

A total of 294 nursery pigs (initially 6.88 ± 0.07 kg BW) were used in a 28-d trial to evaluate the effect of eliminating specific crystalline AA from a low-CP, AA-fortified diet on growth performance. There were 7 pigs per pen and 7 pens per treatment. The positive control diet contained L-Lys·HCl, DL-Met, L-Thr, L-Ile, L-Trp, L-Val, L-Gln, and L-Gly and was the same diet formulation from Exp. 1 where all fish meal was replaced with crystalline AA (Table 3.2). Standardized ileal digestible AA ratios of the positive control diet relative to Lys were 60% Ile, 58% Met and Cys, 64% Thr, 20% Trp, 70% Val, and total Lys:CP of 6.95%. The 6 treatments were (1) positive control, (2) positive control with L-Ile deleted from the diet (52% SID Ile:Lys), (3) positive control with L-Trp deleted (15% SID Trp:Lys), (4) positive control with L-Val deleted (57% SID Val:Lys), (5) positive control with L-Gln and L-Gly deleted (7.51% total Lys:CP), and (6) positive control with L-Ile, L-Trp, L-Val, L-Gln, and L-Gly removed from diet. Treatment 6 served as the negative control and contained SID AA ratios of 52% Ile:Lys, 15% Trp:Lys, 57% Val:Lys, and 7.60% total Lys:CP.

Experiment 3

A total of 282 nursery pigs (initially 7.23 ± 0.07 kg BW) were used in a 28-d growth trial to evaluate the effects of total Lys:CP, using fish meal as a source of non-essential N, on growth performance. Each treatment had 5 replications with 7 pigs per pen and 2 replications with 6 pigs per pen. The 6 total Lys:CP ratios were 6.79, 6.92, 7.06, 7.20, 7.35, and 7.51% (Table 3.3). Standardized ileal digestible Lys of 1.30% was kept constant among treatments. Crystalline L-Lys, DL-Met, L-Thr, L-Trp, and L-Val all increased as fish meal decreased to maintain minimum AA ratios of 58% Met & Cys:Lys, 64% Thr:Lys, 20% Trp:Lys, 52% Ile:Lys, and 70% Val:Lys. Large, 1,270 kg, batches of the 6.79 and 7.51% total Lys:CP diets were manufactured and then blended at ratios of 80:20, 60:40, 40:60, and 20:80, respectively, to achieve the intermediate diets.

Experiment 4

A total of 294 nursery pigs (initially 6.84 ± 0.05 kg BW) were used in a 28-d trial to evaluate the effects of increasing SID Val:Lys on growth performance. There were 7 pigs per pen and 7 pens per treatment. The 6 SID Val:Lys dietary treatments were 57.4, 59.9, 62.3, 64.7, 67.2, and 69.6% (Table 3.4). These ratios were achieved by increasing crystalline L-Val and decreasing corn starch in equal amounts. Large, 1,270 kg, batches of the 57.4 and 69.6% Val diets were manufactured and then blended at ratios of 80:20, 60:40, 40:60, and 20:80, respectively, to achieve the intermediate diets.

Experiment 5

A total of 282 nursery pigs (initially 6.59 ± 0.06 kg BW) were used in a 28-d growth trial to evaluate the effects of replacing high amounts of specialty protein sources with crystalline AA on growth performance. Each treatment had 5 replications with 7 pigs per pen and 2 replications with 6 pigs per pen. Experimental treatments were arranged in a 2 × 3 factorial. Pens were assigned 1 of 3 specialty protein sources including select menhaden fish meal (4.50 vs 1.00%), porcine meat and bone meal (6.00 vs 1.20%), or pet food grade poultry meal (6.00 vs 1.05%). Within protein sources, pens were also assigned either a low or high crystalline AA level (Table 3.5). Specialty protein sources were included at low levels in the high crystalline AA diets to ensure a total Lys:CP ratio no greater than 7.36%. Appropriate amounts of crystalline AA were added to treatment diets in order to maintain SID AA ratios relative to Lys of 52% Ile, 58% Met and Cys, 62% Thr, 16.4% Trp, and 65% Val.

Statistical Analysis

All experiments were analyzed as a completely randomized design with pen as the experimental unit. Data from each experiment were analyzed using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). Experiments 1, 3, and 4 were analyzed using orthogonal polynomial contrasts to determine the effect of decreasing dietary fish meal, increasing dietary total Lys:CP, and increasing SID Val:Lys, respectively. For SID Val:Lys, break-point analysis described by Robbins et al. (2006) was used to determine estimates of requirements. Analysis of variance was performed for Exp 2 and 5. Experiment 5 was analyzed as a 2 × 3 factorial with 2 crystalline AA levels and 3 specialty protein sources. Differences between treatments were determined using the PDIFF statement in SAS. Significant differences for all experiments were declared at $P < 0.05$ and trends declared at $P < 0.10$.

RESULTS AND DISCUSSION

Experiment 1

Analyzed AA levels for experimental diets are shown in Table 3.6. Analyzed concentrations were numerically lower than formulated concentrations, but are within acceptable limits for analytical variation according to AAFCO (2005).

From d 0 to 14 (experimental treatment period), there was no difference (Table 3.7) in ADG, ADFI, or G:F as dietary fish meal decreased and crystalline AA increased. From d 14 to 28 (common diet period), there were no differences in ADG or G:F among treatments. There was a quadratic trend ($P < 0.09$) for ADFI resulting from pigs fed 3.60 and 1.80% fish meal having the numerically lowest intake.

Overall (d 0 to 28), there were no differences in ADG or ADFI. Feed efficiency improved (quadratic; $P < 0.04$), as a result of numeric increases in G:F at the intermediate fish meal levels (2.70 and 1.80% fish meal). Data from this trial suggest that crystalline AA can be used to replace fish meal in diets for 7- to 12-kg pigs. This is in agreement with 3 trials reported by Ratliff et al. (2005b) that used dietary fish meal ranging from 6 to 0% and increasing concentrations of L-Lys·HCl, L-Thr, DL-Met, L-Trp, L-Ile, and L-Val as dietary fish meal decreased. These trials demonstrate that fish meal can be replaced by crystalline AA in nursery diets with no differences in ADG, ADFI, or G:F for 8- to 15-kg pigs.

Bradley et al. (2008) conducted a similar trial evaluating the effect of replacing fish meal with crystalline AA in phase 1 and 2 nursery diets. Fish meal ranged from 8 to 0% and 6 to 0%, respectively. They found no differences in ADG or ADFI during both phases, which is consistent with data from the current study. However, as dietary fish meal decreased and crystalline AA increased, there was a linear decrease in G:F. Bradley et al. (2008) did not include L-Trp or additional sources of nonessential N in the diets, whereas results from Exp. 2 reported herein indicated that both are required in low-CP AA-fortified nursery diets for optimal growth. Numerical differences reported by Bradley et al. (2008) in ADG and ADFI may have resulted from a moderate deficiency in Trp or nonessential N, in turn, explaining the discrepancy in G:F between trials.

The present study, Bradley et al. (2008), and Ratliff et al. (2005b) agree that crystalline AA, when balanced for minimum SID AA ratios, can be used to replace fish meal in diets for 6.8- 11.3-kg pigs. These data established a low-CP, AA-fortified diet that could be used in our subsequent experiments.

Experiment 2

Analyzed AA levels for experimental diets are shown in Table 3.8. Analyzed concentrations were numerically lower than formulated concentrations, but are within acceptable limits for analytical variation according to AAFCO (2005). The AA analysis is in agreement with the design of the experiment, confirming that the specific crystalline AA were removed from the respective diets.

From d 0 to 14 (experimental treatment period), the pigs fed the diet containing no added crystalline Ile had similar ADG, ADFI, and G:F as pigs fed the positive control, but had increased ($P < 0.03$) ADG compared to the pigs fed the other 4 diets (Table 3.9). Pigs fed the diets with deleted L-Trp or L-Val had decreased ($P < 0.03$) ADG and ADFI compared with the pigs fed the positive control diet. Pigs fed the diet without L-Gln and L-Gly had intermediate performance. As expected, feeding the negative control diet resulted in a decrease ($P < 0.01$) in ADG and ADFI. There were no differences in G:F between any of the treatments during the first period, indicating that the response to ADG among treatments was driven primarily by ADFI.

From d 14 to 28, when the common diet was fed, for unknown reasons pigs fed the diet with L-Ile deleted during the previous period had decreased ($P < 0.01$) ADG and poorer ($P < 0.03$) G:F compared with the positive control. Pigs in the other treatment groups had similar ADG and G:F to the positive control. There were no differences in ADFI.

Overall (d 0 to 28), because of the decrease in ADG from d 0 to 14, pigs fed the negative control diet or diets without L-Trp or L-Val had decreased ($P < 0.04$) ADG compared to the pigs fed the positive control. Pigs fed the negative control had decreased ($P < 0.04$) ADFI compared to pigs fed the positive control. There was no difference in G:F for the overall trial.

The positive control diet used during the first period was previously shown to provide adequate AA for optimal growth in nursery pigs from 6.8- to 11.3-kg in Exp. 1. Similar performance between the positive control and the pigs fed the diet with deleted Ile, which contained 60 and 52% SID Ile:Lys respectively, agrees with data from Barea et al. (2009b) that suggests the Ile:Lys requirement of nursery pigs may not be above 50% in diets not containing blood products. Mavromichalis et al. (1998) also confirmed that supplementation of L-Ile is not required in low-protein corn-soybean meal-whey-based diets for optimal growth performance for pigs between 8.8- and 18.5-kg BW. The SID Ile:Lys requirement was not reported by Mavromichalis et al. (1998), but total Ile:Lys requirement was found to be no greater than 60%.

Decreased ADG and ADFI from the pigs fed the diet with deleted L-Trp suggests that feeding 15% SID Trp:Lys was deficient, which is in agreement with the NRC (1998) estimate of 18.5% SID Trp:Lys. Susenbeth (2006) analyzed 33 trials that evaluated the Trp:Lys requirement in pigs. Adjusting for the intervals of Trp:Lys between dietary treatments, 16% SID Trp:Lys was estimated to be the average minimum requirement of the 33 trials. Although this value of 16% is below the NRC (1998) recommendation of 18.5%, both of the values confirm the deficiency of 15% that was detected in the current trial. In agreement, research with growing pigs has reported requirements ranging from 15.6 to 17.1% SID Trp:Lys, and that the requirement may vary depending on the level of other essential AA in the diet (Quant et al., 2007, 2009).

The diet without L-Val (57% SID Val:Lys) was deficient for optimal growth, which agrees with data from other experiments (Mavromichalis et al., 2001; Barea et al., 2009a; Gaines et al., 2010). Although discrepancy exists among research of the SID Val:Lys requirement of nursery pigs, consistent data is available to suggest that it is at least 65% (Wiltafsky et al., 2009; Gaines et al., 2010).

There also was a numerical decrease in performance for pigs fed the diet without L-Gln and L-Gly compared to the positive control. The cause for this slight decrease may be due to the reduction in non-essential N. One method of measuring dietary non-essential N is by calculating dietary Lys:CP. Ratliff et al. (2004) reported their findings as SID Lys and estimated that exceeding 7.00% SID Lys:CP resulted in a decrease in growth performance of nursery pigs from 13- to 26-kg, whereas the calculated value in the diet with L-Gln and L-Gly deleted of 6.80% SID Lys:CP (7.51% total Lys:CP) may be marginally high and approaching the maximum limit. In another study using total Lys, Ratliff et al. (2005a) determined that supplementation of non-essential AA was required in low-CP AA-fortified diets when comparing 2 different total Lys:CP levels (7.1 or 8.1% total Lys:CP) in starter pig diets, and pigs fed 8.1% total Lys:CP had decreased growth performance. Similarly, research with 20- to 50-kg pigs has demonstrated that the combination of Gly and N from an additional AA was required in low-CP, AA-fortified diets for optimal growth (Powell et al., 2009a,b; Southern et al., 2010).

In summary, added L-Trp and L-Val were needed in low-CP, AA-fortified nursery diets to achieve maximum growth performance, whereas the addition of L-Ile was not required. More specifically, SID AA ratios of 15% Trp:Lys and 57% Val:Lys were not adequate for optimal growth, but 52% Ile:Lys was sufficient. The intermediate performance from pigs fed the diet with L-Gln and L-Gly removed seems to indicate a benefit to Gln or Gly either as a source of nonessential N or as individual AA.

Experiment 3

Analyzed AA levels for experimental diets are shown in Table 3.10. Differing from the design of the experiment, analyzed concentrations varied from the formulated values.

From d 0 to 14, there was an trend for increased (quadratic; $P < 0.09$) ADG with increasing dietary total Lys:CP up to 7.35%, with a 13% reduction in ADG when the dietary level increased from 7.35 to 7.51% (Table 3.11). Increasing total Lys:CP tended to increase (quadratic; $P < 0.09$) G:F for pigs fed 7.35%, with a 7% decrease in G:F as total Lys:CP increased to 7.51%.

From d 14 to 28, there was no difference in ADG or G:F. A response (quadratic; $P < 0.04$) was detected for ADFI, which was the result of an increase in ADFI from the pigs fed the intermediate diets (7.06 and 7.20% total Lys:CP) during the previous period.

Overall (d 0 to 28), there was a trend (quadratic; $P < 0.07$) for increased ADG and ADFI caused by the numerically highest values from pigs fed a total Lys:CP of 7.35%

and the numerically lowest values from pigs fed a total Lys:CP of 7.51%. Dietary treatment did not influence G:F for the overall trial.

Limited research has been conducted evaluating the maximum total Lys:CP in pig diets. Lenis et al. (1999) suggested that pigs fed low protein diets fortified with essential AA (EAA) have an increased requirement for N from nonessential AA (NEAA). The reason for this may be due to the N from EAA being utilized for NEAA synthesis when NEAA are not adequately supplied in the diet. NRC (1998) reports that, in pigs, the total CP in muscle typically contains about 6.5 to 7.5% Lys. The difference in the range of Lys:CP may be due to factors such as BW, sex, genotype, or diet composition (Bikker et al., 1994). Mahan et al. (1998) agreed with the NRC (1998) estimate, reporting that the carcass composition of a pig with 8.5-kg live weight contains 7.3% Lys:protein. Based on the information about muscle composition, diets with minimum EAA ratios relative to Lys, but containing an inadequate amount of protein may result in an inefficient use of AA for protein deposition and growth. Data from the current experiment is in common agreement with NRC (1998) and Mahan et al. (1998) muscle composition findings, which indicated that feeding total Lys:CP greater than 7.35% may decrease growth performance of nursery pigs.

Experiment 4

Analyzed AA levels for experimental diets are shown in Table 3.12. Analyzed concentrations were numerically lower than formulated concentrations, but are within acceptable limits for analytical variation according to AAFCO (2005). With the exception of the diets formulated to 59.9 and 62.3% SID Val:Lys having equal analyzed Val, the AA analysis is in agreement with the design of the experiment, confirming that dietary Val increased with increased SID Val:Lys formulations.

From d 0 to 14, ADG and ADFI increased (quadratic; $P < 0.01$) as the SID Val:Lys increased from 57.4 to 64.7%, with little improvement observed thereafter (Table 3.13). Feed efficiency improved (linear; $P < 0.02$) with increasing Val:Lys, but similar to ADG and ADFI, there was little improvement observed in G:F beyond 64.7%.

The requirement for both optimal ADG and G:F was found to be 65% SID Val:Lys by using the 2 slope breakpoint model.

From d 14 to 28, when the common diet was fed, there was no difference in ADG and ADFI; however, G:F became poorer (quadratic; $P < 0.03$) in pigs previously fed increasing Val:Lys. This suggests that the Val level fed from d 0 to 14 had no impact on subsequent ADG and ADFI, but there was a slight compensatory response for G:F.

Overall (d 0 to 28), because of the improvement in ADG and ADFI from d 0 to 14, ADG and ADFI increased (linear; $P < 0.003$) as Val:Lys increased. Again, the greatest improvement in ADG and ADFI was observed in pigs fed the diet containing 64.7% Val:Lys during phase 1. There were no differences in G:F for the overall trial. As a result, a minimum SID Val:Lys of 64.7% was required for optimal growth of 8- to 15-kg pigs.

The predetermined SID Val:Lys ratio of 57.4% used as the lowest dietary treatment is known to be limiting for 7- to 12-kg nursery pigs from Exp. 2, and was confirmed to be deficient by the current experiment. Dietary SID Val:Lys increased up to a maximum level of 69.6%, slightly above the requirement of 68% estimated by the NRC (1998). The minimum SID Val:Lys required for optimal growth in the present study was determined to be 65%. Some literature, such as the NRC (1998) estimate of 68% SID Val:Lys and Barea et al. (2009a) of 70% SID Val:Lys, suggested that our value is too low for optimal performance. However, other recent research demonstrates similar results to the present trial (Wiltafsky et al., 2009; Gaines et al., 2010). Wiltafsky et al. (2009) determined the optimum SID Val requirement to be between 66 to 67% of Lys for 8- to 25-kg pigs. Gaines et al. (2010) reported 3 experiments with pigs ranging from 13- to 32-kg and dietary SID Val:Lys from 56 to 80%. Data from these 3 experiments are in agreement with 65% SID Val:Lys being adequate for optimal growth.

One possible reason for the variation among SID Val:Lys requirements may be a result of the AA levels or digestibility coefficients estimations used in diet formulation. Wiltafsky et al. (2009) used SID AA digestibility coefficients derived from Sauvant et al. (2004), and Barea et al. (2009a) calculated the SID AA using values from the Institut National de la Recherche Agronomique-Association Francaise de Zootechnie (INRA) tables which also originated from Sauvant et al. (2004). The SID values from Sauvaunt et al. (2004) vary slightly from the NRC (1998) values, which were used in the current trial and Gaines et al. (2010). When the 65% SID Val:Lys diet in the present trial is recalculated using SID AA digestibility coefficients from INRA, the SID Val:Lys ratio is 68%, closer to the estimates of Barea et al. (2009a). The minor differences in SID AA calculations may explain some of the discrepancies among trials.

In conclusion, using SID AA coefficients from the NRC (1998), a SID Val:Lys ratio of 65% was sufficient for optimal growth of early nursery pigs.

Experiment 5

Analyzed AA levels for experimental diets are shown in Table 3.14. Analyzed concentrations were numerically lower than formulated concentrations, but are within acceptable limits for analytical variation according to AAFCO (2005).

From d 0 to 14 (experimental treatment period), pigs fed high crystalline AA had improved ($P < 0.04$) ADG compared with pigs fed the low crystalline AA diets (Table 3.15). There was no difference in ADG among pigs fed the different specialty protein sources of fish meal, meat and bone meal, or poultry meal. Average daily feed intake and G:F were similar between pigs fed different crystalline AA levels or different protein sources during the first period.

From d 14 to 28, when the common diet was fed, there were no differences in ADG or ADFI between pigs fed different crystalline AA levels. There was a tendency ($P < 0.09$) for decreased ADG for pigs previously fed meat and bone meal and a tendency ($P < 0.09$) for increased ADFI for pigs previously fed poultry meal. These tendencies resulted in increased ($P < 0.03$) G:F for pigs previously fed fish meal during phase 1 compared to pigs fed diets containing meat and bone meal or poultry meal. There was no difference between pigs fed different crystalline AA levels during the second period.

Overall (d 0 to 28), dietary crystalline AA had no impact on ADG, ADFI, or G:F. Pigs fed diets containing fish meal from d 0 to 14 tended ($P < 0.08$) to have increased ADG and G:F for the overall trial compared to pigs fed diets containing meat and bone meal or poultry meal. There was no difference in ADFI among pigs fed different protein sources. This data suggests that crystalline AA can be used to replace specialty protein sources in nursery pig diets without negatively influencing growth.

Frantz et al. (2005) also found that specialty proteins can be replaced by crystalline AA in phase 2 nursery diets in an experiment that evaluated the effects of replacing SBM with either 4.5% fish meal, 5% poultry meal, or crystalline AA, including L-Lys·HCl, L-Thr, DL-Met, L-Val, L-Ile, and L-Trp. Similar to the current experiment, for unknown reasons pigs fed the low-CP AA-fortified diet had increased ADG compared to pigs fed fish meal or poultry meal. However, there was also an improvement in G:F observed in the pigs fed the high crystalline AA diet, whereas in the current trial there were no differences in G:F among pigs fed the different dietary treatments. Other experiments also suggest that fish meal can be replaced in nursery diets by crystalline AA with no negative effects on growth performance (Ratliff et al., 2005b; Bradley et al., 2008).

Earlier trials reporting that specialty protein sources cannot be replaced with crystalline AA may be a result of inadequate non-essential N or AA deficiencies due to diets only formulated to the second or third limiting AA, such as Kats et al. (1994) which only included crystalline Lys and Met when attempting to replace specialty protein sources. Davis et al. (1997) and de Rodas et al. (1997) found that whey protein concentrate could not be replaced by an ideal mixture of crystalline AA in weanling pigs without negatively influencing growth performance. However, these experiments were reported in abstracts, and the crystalline AA added or AA ratios were not given. Chung et al. (1999) conducted a similar experiment evaluating the replacement of whey protein concentrate with crystalline AA in early nursery diets. Growth performance decreased when whey protein concentrate was replaced by, what was described as, an ideal mixture of crystalline Lys, Thr, Met, Trp, Val, and Ile; however, pigs fed a diet containing the ideal mixture plus additional supplementation of Phe, Tyr, and Trp had similar growth performance to those fed the diet containing whey protein concentrate. Data was presented in an abstract and did not report the AA ratios of the diet, but the results suggested that whey protein concentrate can be replaced by crystalline AA, and the addition of Phe, Tyr, and Trp was required for optimal growth as a source of non-essential N, specific AA, or both. The combination of data from these experiments indicate that additional AA, either to meet the needs of third or fourth limiting AA or as a source of non-essential AA, are required to replace specialty protein sources with crystalline AA.

In conclusion, these results indicate that crystalline AA in nursery pigs diets can replace fish meal, meat and bone meal, and poultry meal when balanced for minimum SID AA ratios and a maximum total Lys:CP with no negative effect on growth performance.

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FIGURES AND TABLES

Table 3.1 Composition of diets, Exp. 1 (as-fed-basis)[1]

	Fish meal, %[2]						Common
Item	4.50	3.60	2.70	1.80	0.90	0.00	phase 2[3]
Ingredient, %							
Corn	56.58	56.83	57.07	57.53	57.57	57.81	65.05
Soybean meal (46.5% CP)	25.21	25.21	25.20	25.20	25.20	25.19	30.73
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	10.00	---
Select menhaden fish meal	4.50	3.60	2.70	1.80	0.90	---	---
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	---
Monocalcium phosphate (21% P)	0.51	0.63	0.75	0.86	0.98	1.10	1.08
Limestone	0.55	0.62	0.69	0.76	0.83	0.90	0.95
Salt	0.30	0.31	0.32	0.33	0.34	0.35	0.35
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25	-
Trace mineral premix[4]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix[5]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lys·HCl	0.275	0.327	0.379	0.430	0.482	0.534	0.360
DL-Met	0.124	0.143	0.162	0.182	0.201	0.220	0.130
L-Thr	0.136	0.155	0.174	0.192	0.211	0.230	0.130
L-Trp	0.046	0.051	0.056	0.060	0.065	0.070	---
L-Ile	---	0.02	0.04	0.06	0.08	0.10	---
L-Val	0.037	0.062	0.086	0.111	0.135	0.160	---
L-Gln	---	0.16	0.32	0.48	0.64	0.80	---
L-Gly	---	0.16	0.32	0.48	0.64	0.80	---
Phytase[6]	0.085	0.085	0.085	0.085	0.085	0.085	0.165
TOTAL	100	100	100	100	100	100	100
Calculated analysis							
Standardized ileal digestible (SID) amino acids, %							
Lys	1.30	1.30	1.30	1.30	1.30	1.30	1.26
Ile:Lys	60	60	60	60	60	60	61
Leu:Lys	125	122	119	116	114	111	129
Met:Lys	35	35	35	36	36	36	33
Met & Cys:Lys	58	58	58	58	58	58	58
Thr:Lys	64	64	64	64	64	64	63
Trp:Lys	20	20	20	20	20	20	17.4
Val:Lys	70	70	70	70	70	70	68
Total Lys, %	1.43	1.43	1.43	1.42	1.42	1.42	1.39
ME, kcal/kg	3,369	3,366	3,362	3,358	3,355	3,351	3,314
SID Lys:ME, g/Mcal	3.86	3.86	3.87	3.87	3.87	3.88	3.80
CP, %	21.1	20.9	20.8	20.6	20.5	20.3	20.8
Total Lys:CP, %	6.78	6.84	6.88	6.89	6.93	7.00	6.68
Ca, %	0.72	0.72	0.72	0.72	0.72	0.72	0.69
P, %	0.65	0.65	0.64	0.64	0.64	0.64	0.62
Available P, %	0.47	0.47	0.47	0.47	0.47	0.47	0.42

[1]A total of 282 nursery pigs (PIC TR4 × 1050) were used in a 28-d trial to evaluate the effects of replacing fish meal with crystalline amino acids on growth performance.

[2]Treatment diets were fed from d 0 to 14.

[3]Common diet was fed from d 14 to 28.

[4]Trace mineral premix provided per kg of complete feed: 16.5 mg of Cu from $CuSO_4 \cdot 5H^20$, 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$, 165 mg of Fe as $FeSO_4H_2O$, 39.7 mg of Mn as $MnSO_4 \cdot H20$, 0.30 mg of Se as Na_2SeO_3, and 165 mg of Zn as $ZnSO_4$.

[5]Vitamin premix provided per kg of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B_{12}, 50.0 mg of niacin, 27.6 mg of pantothenic acid, and 8.3 mg of riboflavin.

[6]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 509 FTU/kg, with a release of 0.10% available P.

Table 3.2 Composition of diets, Exp. 2 (as-fed-basis)[1,2]

Item	Positive Control	Crystalline AA removed from the diet -Ile	-Trp	-Val	-Gly/Gln	Negative Control	Common Phase 2
Ingredient, %							
Corn	58.15	58.15	58.15	58.15	58.15	58.15	65.05
Soybean meal (46.5% CP)	25.20	25.20	25.20	25.20	25.20	25.20	30.73
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	10.00	---
Corn starch	---	0.10	0.07	0.16	1.26	1.59	---
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	---
Monocalcium phosphate (21% P)	1.10	1.10	1.10	1.10	1.10	1.10	1.08
Limestone	0.90	0.90	0.90	0.90	0.90	0.90	0.95
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25	-
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix[4]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lys·HCl	0.533	0.533	0.533	0.533	0.533	0.533	0.360
DL-Met	0.220	0.220	0.220	0.220	0.220	0.220	0.130
L-Thr	0.230	0.230	0.230	0.230	0.230	0.230	0.130
L-Trp	0.070	0.070	---	0.070	0.070	---	---
L-Ile	0.100	---	0.100	0.100	0.100	---	---
L-Val	0.160	0.160	0.160	---	0.160	---	---
Gln	0.630	0.630	0.630	0.630	---	---	---
Gly	0.630	0.630	0.630	0.630	---	---	---
Phytase 600[5]	0.085	0.085	0.085	0.085	0.085	0.085	0.165
TOTAL	100	100	100	100	100	100	100
Calculated analysis							
Standardized ileal digestible (SID) amino acids, %							
Lys	1.30	1.30	1.30	1.30	1.30	1.30	1.26
Ile:Lys	60	52	60	60	60	52	61
Leu:Lys	111	111	111	111	111	111	129
Met:Lys	36	36	36	36	36	36	33
Met & Cys:Lys	58	58	58	58	58	58	58
Thr:Lys	64	64	64	64	64	64	63
Trp:Lys	20	20	15	20	20	15	17.4
Val:Lys	70	70	70	57	70	57	68
Total Lys, %	1.42	1.42	1.42	1.42	1.42	1.42	1.39
ME, kcal/kg	3,342	3,342	3,342	3,342	3,342	3,342	3,314
SID Lys:ME, g/Mcal	5.27	5.28	5.27	5.28	5.23	5.24	3.80
CP, %	20.4	20.4	20.4	20.3	18.9	18.7	20.8
Total Lys:CP, %	6.96	6.96	6.96	7.00	7.51	7.60	6.68
Ca, %	0.72	0.72	0.72	0.72	0.72	0.72	0.69
P, %	0.64	0.64	0.64	0.64	0.64	0.64	0.62
Available P, %	0.47	0.47	0.47	0.47	0.47	0.47	0.42

[1]A total of 294 nursery pigs (PIC TR4 × 1050) were used in a 28-d trial to evaluate the effects deleting crystalline amino acids from a low-CP, AA-fortified diet.

[2]Treatment diets were fed from d 0 to 14, and a common diet was fed from d 14 to 28.

[3]Trace mineral premix provided per kg of complete feed: 16.5 mg of Cu from $CuSO_4 \cdot 5H^20$, 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$, 165 mg of Fe as $FeSO_4H_2O$, 39.7 mg of Mn as $MnSO_4 \cdot H20$, 0.30 mg of Se as Na_2SeO_3, and 165

mg of Zn as $ZnSO_4$.

[4]Vitamin premix provided per kg of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B_{12}, 50.0 mg of niacin, 27.6 mg of pantothenic acid, and 8.3 mg of riboflavin.

[5]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 509 FTU/kg, with a release of 0.10% available P.

Table 3.3 Composition of diets, Exp. 3 (as-fed-basis)[1]

Item	Total Lys:CP, %[2]						Common Phase 2[3]
	6.79	6.92	7.06	7.20	7.35	7.51	
Ingredient, %							
Corn	56.58	57.19	57.79	58.40	59.01	59.62	65.05
Soybean meal (46.5% CP)	25.21	25.18	25.16	25.14	25.11	25.09	30.73
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	10.00	---
Select menhaden fish meal	4.50	3.60	2.70	1.80	0.90	---	---
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	---
Monocalcium phosphate (21% P)	0.51	0.63	0.75	0.86	0.98	1.10	1.08
Limestone	0.55	0.62	0.69	0.76	0.83	0.90	0.95
Salt	0.30	0.31	0.32	0.33	0.34	0.35	0.35
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25	---
Trace mineral premix[4]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix[5]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lys·HCl	0.275	0.327	0.378	0.430	0.481	0.533	0.360
DL-Met	0.124	0.143	0.162	0.182	0.201	0.220	0.130
L-Thr	0.136	0.155	0.174	0.192	0.211	0.230	0.130
L-Trp	0.046	0.051	0.056	0.060	0.065	0.070	---
L-Val	0.037	0.062	0.086	0.111	0.135	0.160	---
Phytase[6]	0.085	0.085	0.085	0.085	0.085	0.085	0.165
TOTAL	100	100	100	100	100	100	100
Calculated analysis							
Standardized ileal digestible (SID) amino acids, %							
Lys	1.30	1.30	1.30	1.30	1.30	1.30	1.26
Ile:Lys	60	59	57	55	54	52	61
Leu:Lys	125	122	120	117	114	112	129
Met:Lys	35	35	35	36	36	37	33
Met & Cys:Lys	58	58	58	58	58	58	58
Thr:Lys	64	64	64	64	64	64	63
Trp:Lys	20	20	20	20	20	20	17.4
Val:Lys	70	70	70	70	70	70	68
Total Lys, %	1.43	1.43	1.43	1.43	1.42	1.42	1.39
ME, kcal/kg	3,369	3,365	3,360	3,355	3,351	3,346	3,314
SID Lys:ME, g/Mcal	3.86	3.86	3.87	3.87	3.88	3.89	3.80
CP, %	21.1	20.6	20.2	19.8	19.4	18.9	20.8
Ca, %	0.72	0.72	0.72	0.72	0.72	0.72	0.69
P, %	0.65	0.65	0.65	0.65	0.64	0.64	0.62
Available P, %	0.47	0.47	0.47	0.47	0.47	0.47	0.42

[1]A total of 282 nursery pigs (PIC TR4 × 1050) were used in a 28-d trial to evaluate the effects of total Lys:CP on growth performance.

[2]Treatment diets were fed from d 0 to 14.

[3]Common diet was fed from d 14 to 28.

[4]Trace mineral premix provided per kg of complete feed: 16.5 mg of Cu from $CuSO_4 \cdot 5H^20$, 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$, 165 mg of Fe as $FeSO_4H_2O$, 39.7 mg of Mn as $MnSO_4 \cdot H20$, 0.30 mg of Se as Na_2SeO_3, and 165 mg of Zn as $ZnSO_4$.

[5]Vitamin premix provided per kg of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B_{12}, 50.0 mg of niacin, 27.6 mg of pantothenic acid,

and 8.3 mg of riboflavin.
[6]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 509 FTU/kg, with a release of 0.10% available P.

Table 3.4 Composition of diets, Exp. 4 (as-fed-basis)[1]

	Standardized ileal digestible Val:Lys, %[2]						Common
Item	57.4	59.9	62.3	64.7	67.2	69.6	phase 2[3]
Ingredient, %							
Corn	58.26	58.26	58.26	58.26	58.26	58.26	65.05
Soybean meal (46.5% CP)	25.19	25.19	25.19	25.19	25.19	25.19	30.73
Spray-dried whey	10.00	10.00	10.00	10.00	10.00	10.00	---
Corn starch	0.160	0.128	0.096	0.064	0.032	---	---
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	---
Monocalcium phosphate (21% P)	1.10	1.10	1.10	1.10	1.10	1.10	1.08
Limestone	0.90	0.90	0.90	0.90	0.90	0.90	0.95
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Zinc oxide	0.25	0.25	0.25	0.25	0.25	0.25	---
Trace mineral premix[4]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix[5]	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lys·HCl	0.533	0.533	0.533	0.533	0.533	0.533	0.360
DL-Met	0.220	0.220	0.220	0.220	0.220	0.220	0.130
L-Thr	0.230	0.230	0.230	0.230	0.230	0.230	0.130
L-Trp	0.070	0.070	0.070	0.070	0.070	0.070	---
L-Val	---	0.032	0.064	0.096	0.128	0.160	---
L-Gln	0.630	0.630	0.630	0.630	0.630	0.630	---
L-Gly	0.630	0.630	0.630	0.630	0.630	0.630	---
Phytase[6]	0.085	0.085	0.085	0.085	0.085	0.085	0.165
TOTAL	100	100	100	100	100	100	100
Calculated analysis							
Standardized ileal digestible (SID) amino acids, %							
Lys	1.30	1.30	1.30	1.30	1.30	1.30	1.26
Ile:Lys	52	52	52	52	52	52	61
Leu:Lys	111	111	111	111	111	111	129
Met:Lys	36	36	36	36	36	36	33
Met & Cys:Lys	58	58	58	58	58	58	58
Thr:Lys	64	64	64	64	64	64	63
Trp:Lys	20	20	20	20	20	20	17.4
Val:Lys	57.4	59.9	62.3	64.7	67.2	69.6	68
Total Lys, %	1.42	1.42	1.42	1.42	1.42	1.42	1.39
ME, kcal/kg	3,342	3,342	3,342	3,342	3,342	3,342	3,314
SID Lys:ME, g/Mcal	3.89	3.89	3.89	3.89	3.89	3.89	3.80
CP, %	20.2	20.3	20.3	20.3	20.3	20.4	20.8
Ca, %	0.72	0.72	0.72	0.72	0.72	0.72	0.69
P, %	0.64	0.64	0.64	0.64	0.64	0.64	0.62
Available P, %	0.47	0.47	0.47	0.47	0.47	0.47	0.42

[1]A total of 294 nursery pigs (PIC TR4 × 1050) were used in a 28-d trial to evaluate the effects of SID Val:Lys on growth performance.

[2]Treatment diets were fed from d 0 to 14.

[3]Common diet was fed from d 14 to 28.

[4]Trace mineral premix provided per kg of complete feed: 16.5 mg of Cu from $CuSO_4 \cdot 5H^20$, 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$, 165 mg of Fe as $FeSO_4H_2O$, 39.7 mg of Mn as $MnSO_4 \cdot H20$, 0.30 mg of Se as Na_2SeO_3, and 165 mg of Zn as $ZnSO_4$.

[5]Vitamin premix provided per kg of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B_{12}, 50.0 mg of niacin, 27.6 mg of pantothenic acid, and 8.3 mg of riboflavin.

[6]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 509 FTU/kg, with a release of 0.10% available P.

Table 3.5 Composition of diets, Exp. 5 (as-fed-basis)[1]

Item	Crystalline AA level: / Protein source:	Phase 1[2] Low Fish Meal	Low Meat and Bone Meal	Low Poultry Meal	High Fish Meal	High Meat and Bone Meal	High Poultry Meal	Common phase 2[3]
Ingredient, %								
Corn		56.72	56.03	54.54	59.01	59.07	58.98	65.05
Soybean meal (46.5% CP)		25.20	25.20	25.20	25.27	25.20	25.20	30.73
Spray-dried whey		10.00	10.00	10.00	10.00	10.00	10.00	---
Select menhaden fish meal		4.50	---	---	1.00	---	---	---
Meat and bone meal		---	6.00	---	---	1.20	---	---
Poultry meal		---	---	6.00	---	---	1.00	---
Soybean oil		1.00	1.00	1.00	1.00	1.00	1.00	---
Monocalcium phosphate (21% P)		0.50	---	0.40	1.00	0.85	1.00	1.08
Limestone		0.55	---	0.40	0.75	0.65	0.75	0.95
Salt		0.30	0.30	0.30	0.30	0.30	0.30	0.35
Zinc oxide		0.25	0.25	0.25	0.25	0.25	0.25	-
Trace mineral premix[4]		0.15	0.15	0.15	0.15	0.15	0.15	0.15
Vitamin premix[5]		0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lys·HCl		0.275	0.385	0.310	0.470	0.500	0.495	0.360
DL-Met		0.125	0.180	0.140	0.200	0.205	0.200	0.130
L-Thr		0.100	0.140	0.100	0.175	0.195	0.190	0.130
L-Trp		---	0.010	---	0.018	0.020	0.020	---
L-Val		---	0.015	---	0.070	0.080	0.075	---
Phytase[6]		0.085	0.085	0.085	0.085	0.085	0.085	0.165
TOTAL		100	100	100	100	100	100	100
Calculated analysis								
Standardized ileal digestible (SID) amino acids, %								
Lys		1.30	1.30	1.30	1.30	1.30	1.30	1.26
Ile:Lys		60	57	60	54	53	54	61
Leu:Lys		125	121	125	115	114	114	129
Met:Lys		35	36	34	36	36	36	33
Met & Cys:Lys		58	58	58	58	58	58	58
Thr:Lys		62	62	62	62	62	62	63
Trp:Lys		16.7	16.4	16.5	16.5	16.4	16.5	17.4
Val:Lys		67	65	66	65	65	65	68
Total Lys, %		1.43	1.45	1.46	1.42	1.43	1.43	1.39
ME, kcal/kg		3,369	3,366	3,362	3,358	3,355	3,351	3,314
SID Lys:ME, g/Mcal		3.86	3.89	3.89	3.88	3.88	3.88	3.80
CP, %		21.0	21.4	22.4	19.4	19.4	19.4	20.8
Total Lys:CP, %		6.82	6.78	6.53	7.35	7.36	7.36	6.68
Ca, %		0.71	0.78	0.71	0.70	0.70	0.70	0.69
P, %		0.65	0.70	0.65	0.65	0.65	0.65	0.62
Available P, %		0.47	0.50	0.47	0.48	0.47	0.47	0.42

[1]A total of 282 nursery pigs (PIC TR4 × 1050) were used in a 28-d trial to evaluate the effects of replacing high amounts of fish meal, meat and bone meal, and poultry meal with crystalline AA on growth performance.

[2]Treatment diets were fed from d 0 to 14.

[3]Common diet was fed from d 14 to 28.

[4]Trace mineral premix provided per kg of complete feed: 16.5 mg of Cu from $CuSO_4 \cdot 5H^20$, 0.30 mg of I as $C_2H_2(NH_2)_2 \cdot 2HI$, 165 mg of Fe as $FeSO_4H_2O$, 39.7 mg of Mn as $MnSO_4 \cdot H20$, 0.30 mg of Se as Na_2SeO_3, and 165 mg of Zn as $ZnSO_4$.

[5]Vitamin premix provided per kg of complete feed: 11,023 IU of vitamin A, 1,377 IU of vitamin D, 44.1 IU of vitamin E, 4.4 mg of vitamin K, 0.04 mg of vitamin B_{12}, 50.0 mg of niacin, 27.6 mg of pantothenic acid, and 8.3 mg of riboflavin.

[6]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 509 FTU/kg, with a release of 0.10% available P.

Table 3.6 Analyzed nutrient composition of diets, Exp. 1 (as-fed-basis)[1]

	Fish Meal, %					
Item, %	4.50	3.60	2.70	1.80	0.90	0.00
CP	20.3[2] (21.0)[3]	20.9 (20.9)	19.6 (20.8)	19.9 (20.6)	20.1 (20.5)	18.8 (20.4)
Lys	1.25 (1.42)	1.19 (1.42)	1.24 (1.42)	1.25 (1.42)	1.30 (1.42)	1.19 (1.42)
Ile	0.81 (0.88)	0.73 (0.88)	0.81 (0.88)	0.74 (0.87)	0.73 (0.87)	0.76 (0.87)
Leu	1.50 (1.80)	1.44 (1.76)	1.47 (1.72)	1.47 (1.68)	1.41 (1.64)	1.39 (1.60)
Met	0.37 (0.48)	0.37 (0.49)	0.39 (0.49)	0.38 (0.49)	0.39 (0.50)	0.38 (0.50)
Met + Cys	0.60 (0.83)	0.64 (0.83)	0.65 (0.83)	0.62 (0.83)	0.60 (0.82)	0.64 (0.82)
Thr	0.81 (0.96)	0.90 (0.95)	0.86 (0.95)	0.89 (0.94)	0.85 (0.94)	0.83 (0.93)
Trp	0.29 (0.29)	0.32 (0.29)	0.33 (0.29)	0.32 (0.29)	0.32 (0.29)	0.28 (0.29)
Val	0.88 (1.03)	0.86 (1.02)	0.86 (1.02)	0.86 (1.02)	0.88 (1.02)	0.85 (1.02)

[1]A total of 282 nursery pigs (PIC TR4 × 1050) were used in a 28-d trial to evaluate the effects of replacing fish meal with crystalline amino acids on growth performance.

[2]A representative sample of each diet was collected and analyzed for amino acid composition.

[3]Values in parentheses indicate formulated values.

Table 3.7 Evaluation of replacing fish meal with crystalline amino acids on growth performance in nursery pig diets (Exp. 1)[1,2]

	Fish meal, %							Probability, *P* <	
Item	4.50	3.60	2.70	1.80	0.90	0.00	SEM	Linear	Quadratic
d 0 to 14									
ADG, g	376	372	389	378	380	380	10.70	0.71	0.73
ADFI, g	528	517	537	525	531	546	15.84	0.38	0.62
G:F	0.713	0.720	0.730	0.719	0.715	0.698	0.018	0.52	0.29
d 14 to 28									
ADG, g	579	553	579	527	562	548	13.24	0.11	0.45
ADFI, g	953	906	944	860	935	919	18.88	0.31	0.09
G:F	0.608	0.610	0.614	0.614	0.601	0.596	0.009	0.25	0.22
d 0 to 28									
ADG, g	477	462	484	452	471	464	8.92	0.34	0.71
ADFI, g	741	712	739	693	733	733	14.41	0.86	0.16
G:F	0.645	0.650	0.654	0.653	0.642	0.634	0.007	0.14	0.04
BW, kg									
d 0	7.27	7.31	7.26	7.34	7.33	7.29	0.075	0.68	0.70
d 14	12.53	12.52	12.71	12.63	12.65	12.62	0.183	0.64	0.66
d 28	20.64	20.26	20.72	20.01	20.51	20.29	0.299	0.50	0.74

[1] A total of 282 nursery pigs (PIC TR4 × 1050) were used in a 28-d trial to evaluate the effects of replacing fish meal with crystalline AA on growth performance. Values represent the means of 7 pens per treatment.
[2] Treatment diets were fed from d 0 to 14 and a common diet fed from d 14 to 28.

Table 3.8 Analyzed nutrient composition of diets, Exp. 2 (as-fed-basis)[1]

	Positive	Crystalline AA removed from the diet				Negative
Item, %	control	-Ile	-Trp	-Val	-Gly/Gln	control
CP	19.3[2] (20.4)[3]	20.1 (20.4)	19.5 (20.4)	20.6 (20.3)	18.9 (18.9)	18.3 (18.7)
Lys	1.16 (1.42)	1.26 (1.42)	1.20 (1.42)	1.28 (1.42)	1.23 (1.42)	1.30 (1.42)
Ile	0.72 (0.87)	0.68 (0.77)	0.73 (0.87)	0.81 (0.87)	0.76 (0.87)	0.72 (0.77)
Leu	1.39 (1.61)	1.41 (1.61)	1.37 (1.61)	1.45 (1.61)	1.42 (1.61)	1.41 (1.61)
Met	0.37 (0.50)	0.39 (0.50)	0.38 (0.50)	0.39 (0.50)	0.39 (0.50)	0.38 (0.50)
Met + Cys	0.61 (0.82)	0.64 (0.82)	0.62 (0.82)	0.65 (0.82)	0.64 (0.82)	0.63 (0.82)
Thr	0.77 (0.93)	0.80 (0.93)	0.78 (0.93)	0.84 (0.93)	0.79 (0.93)	0.77 (0.93)
Trp	0.27 (0.29)	0.26 (0.29)	0.23 (0.22)	0.27 (0.29)	0.20 (0.29)	0.24 (0.22)
Val	0.84 (1.02)	0.89 (1.02)	0.88 (1.02)	0.80 (0.86)	0.87 (1.02)	0.78 (0.86)

[1]A total of 294 nursery pigs (PIC TR4 × 1050) were used in a 28-d trial to evaluate the effects deleting crystalline amino acids from a low-CP, AA-fortified diet.

[2]A representative sample of each diet was collected and analyzed for amino acid composition.

[3]Values in parentheses indicate formulated values.

Table 3.9 Effects of deleting crystalline amino acids from low-CP, amino acid-fortified diets on growth performance in nursery pigs (Exp. 2)[1,2]

	Positive control[3]	Crystalline AA removed from the diet				Negative control[4]	SEM
		-Ile	-Trp	-Val	-Gly/Gln		
d 0 to 14							
ADG, g	303[bc]	320[c]	256[a]	246[a]	277[ab]	244[a]	13.44
ADFI, g	420[b]	433[b]	367[a]	345[a]	390[ab]	345[a]	16.12
G:F	0.723	0.738	0.697	0.711	0.709	0.703	0.016
d 14 to 28							
ADG, g	536[b]	475[a]	504[ab]	522[b]	530[b]	523[b]	14.27
ADFI, g	854	801	807	831	862	816	25.30
G:F	0.630[b]	0.593[a]	0.626[b]	0.629[b]	0.616[ab]	0.642[b]	0.011
d 0 to 28							
ADG, g	420[b]	397[ab]	380[a]	384[a]	403[ab]	384[a]	12.02
ADFI, g	637[b]	617[ab]	587[ab]	588[ab]	626[ab]	581[a]	19.13
G:F	0.661	0.644	0.648	0.653	0.645	0.660	0.010
BW, kg							
d 0	6.89	6.89	6.87	6.88	6.88	6.86	0.066
d 14	11.14[bc]	11.36[c]	10.45[a]	10.32[a]	10.76[ab]	10.28[a]	0.212
d 28	18.65[b]	18.01[ab]	17.51[a]	17.63[a]	18.18[ab]	17.60[a]	0.355

[1] A total of 294 nursery pigs (PIC TR4 × 1050) were used in a 28-d growth trial to evaluate the of deleting crystalline AA from a low-CP, AA-fortified diet on growth performance. Values represent the means of 7 pens per treatment.
[2] Treatment diets were fed from d 0 to 14 and a common diet fed from d 14 to 28.
[3] Contained crystalline Lys, Met, Thr, Ile, Trp, Val, Gln, and Gly.
[4] Positive control diet with removal of crystalline Ile, Trp, Val, Gln, and Gly.
[abc] Within a row, means without a common superscript differ ($P < 0.05$).

Table 3.10 Analyzed nutrient composition of diets, Exp. 3 (as-fed-basis)[1]

	Total Lys:CP, %					
Item, %	6.79	6.92	7.06	7.20	7.35	7.51
CP	21.1[2] (21.1)[3]	19.4 (20.6)	19.0 (20.2)	20.5 (19.8)	18.2 (19.4)	17.5 (18.9)
Lys	1.43 (1.43)	1.35 (1.43)	1.29 (1.43)	1.38 (1.43)	1.26 (1.42)	1.05 (1.42)
Ile	0.77 (0.88)	0.73 (0.86)	0.70 (0.84)	0.76 (0.81)	0.70 (0.79)	0.63 (0.77)
Leu	1.55 (1.80)	1.50 (1.76)	1.46 (1.72)	1.53 (1.69)	1.44 (1.65)	1.37 (1.62)
Met	0.45 (0.48)	0.43 (0.49)	0.41 (0.49)	0.45 (0.50)	0.41 (0.50)	0.40 (0.50)
Met + Cys	0.74 (0.83)	0.72 (0.83)	0.69 (0.83)	0.75 (0.83)	0.70 (0.83)	0.66 (0.83)
Thr	0.94 (0.96)	0.93 (0.95)	0.89 (0.95)	0.95 (0.94)	0.87 (0.94)	0.77 (0.94)
Trp	0.30 (0.29)	0.22 (0.29)	0.26 (0.29)	0.29 (0.29)	0.28 (0.29)	0.26 (0.29)
Val	0.99 (1.03)	0.96 (1.02)	0.93 (1.02)	0.98 (1.02)	0.90 (1.02)	0.81 (1.02)

[1]A total of 282 nursery pigs (PIC TR4 × 1050) were used in a 28-d trial to evaluate the effects of total Lys: CP on growth performance.

[2]A representative sample of each diet was collected and analyzed for amino acid composition.

[3]Values in parentheses indicate formulated values.

Table 3.11 Evaluation of total lysine:CP on growth performance in nursery pigs (Exp. 3)[1,2]

	Total Lys:CP, %							Probability, $P <$	
	6.79	6.92	7.06	7.20	7.35	7.51	SEM	Linear	Quadratic
d 0 to 14									
ADG, g	347	358	358	356	387	336	11.55	0.72	0.09
ADFI, g	479	503	498	489	533	495	14.84	0.20	0.39
G:F	0.726	0.710	0.720	0.727	0.700	0.679	0.012	0.09	0.09
d 14 to 28									
ADG, g	513	512	526	536	513	508	13.68	0.90	0.19
ADFI, g	821	841	845	846	838	795	18.96	0.38	0.04
G:F	0.625	0.609	0.620	0.635	0.600	0.639	0.012	0.26	0.42
d 0 to 28									
ADG, g	430	435	442	446	450	422	10.25	0.91	0.07
ADFI, g	650	672	672	668	686	645	14.22	0.92	0.07
G:F	0.662	0.647	0.660	0.668	0.700	0.654	0.011	0.99	0.68
BW, kg									
d 0	7.22	7.22	7.22	7.27	7.22	7.20	0.066	0.97	0.87
d 14	12.07	12.23	12.23	12.26	12.65	11.91	0.190	0.92	0.46
d 28	19.26	19.40	19.59	19.77	19.83	19.02	0.311	0.99	0.44

[1] A total of 282 nursery pigs (PIC TR4 × 1050) were used in a 28-d growth trial to evaluate the effects of total Lys:CP on growth performance. Values represent the means of 7 pens per treatment.
[2] Treatment diets were fed from d 0 to 14 and a common diet fed from d 14 to 28.

Table 3.12 Analyzed nutrient composition of diets, Exp. 4 (as-fed-basis)[1]

	Standardized ileal digestible Val:Lys, %					
Item, %	57.4	59.9	62.3	64.7	67.2	69.6
CP	19.0[2] (20.4)[3]	18.3 (20.3)	18.9 (20.3)	19.4 (20.3)	19.0 (20.3)	19.2 (20.2)
Lys	1.18 (1.42)	1.18 (1.42)	1.14 (1.42)	1.21 (1.42)	1.13 (1.42)	1.16 (1.42)
Ile	0.69 (0.73)	0.69 (0.73)	0.67 (0.73)	0.70 (0.73)	0.66 (0.73)	0.67 (0.73)
Leu	1.42 (1.61)	1.43 (1.61)	1.39 (1.61)	1.45 (1.61)	1.35 (1.61)	1.38 (1.61)
Met	0.38 (0.50)	0.40 (0.50)	0.38 (0.50)	0.39 (0.50)	0.39 (0.50)	0.40 (0.50)
Met + Cys	0.64 (0.82)	0.66 (0.82)	0.64 (0.82)	0.66 (0.82)	0.64 (0.82)	0.66 (0.82)
Thr	0.86 (0.93)	0.86 (0.93)	0.85 (0.93)	0.88 (0.93)	0.81 (0.93)	0.82 (0.93)
Trp	0.29 (0.29)	0.31 (0.29)	0.35 (0.29)	0.33 (0.29)	0.30 (0.29)	0.29 (0.29)
Val	0.79 (0.86)	0.82 (0.89)	0.82 (0.92)	0.87 (0.95)	0.88 (0.99)	0.90 (1.02)

[1]A total of 294 nursery pigs (PIC TR4 × 1050) were used in a 28-d trial to evaluate the effects of SID Val:Lys on growth performance.

[2]A representative sample of each diet was collected and analyzed for amino acid composition.

[3]Values in parentheses indicate formulated values.

Table 3.13 Evaluation of SID valine:lysine on growth performance in nursery pigs (Exp. 4)[1,2]

	SID Val:Lys, %							Probability, *P* <	
	57.4	59.9	62.3	64.7	67.2	69.9	SEM	Linear	Quadratic
d 0 to 14									
ADG, g	198	238	266	292	295	298	10.30	<0.0001	0.005
ADFI, g	316	359	418	427	440	434	15.69	<0.0001	0.01
G:F	0.629	0.670	0.636	0.700	0.674	0.690	0.019	0.02	0.82
d 14 to 28									
ADG, g	480	481	491	486	464	485	17.36	0.82	0.86
ADFI, g	763	783	807	824	784	802	25.68	0.33	0.27
G:F	0.630	0.610	0.607	0.600	0.592	0.610	0.008	0.01	0.03
d 0 to 28									
ADG, g	339	360	378	389	379	392	12.41	0.003	0.18
ADFI, g	540	571	613	626	612	618	19.27	0.002	0.06
G:F	0.629	0.630	0.617	0.600	0.621	0.630	0.009	0.998	0.22
BW, kg									
d 0	6.84	6.85	6.85	6.85	6.84	6.84	0.049	0.97	0.93
d 14	9.61	10.18	10.56	10.94	10.97	11.02	0.169	<0.0001	0.01
d 28	16.33	16.92	17.43	17.75	17.47	17.80	0.362	0.004	0.19

[1] A total of 294 nursery pigs (PIC TR4 × 1050) were used in a 28-d growth trial to evaluate the effects of SID Val:Lys on growth performance. Values represent the means of 7 pens per treatment.
[2] Treatment diets were fed from d 0 to 14, and a common diet was fed from d 14 to 28.

Table 3.14 Analyzed nutrient composition of diets, Exp. 5 (as-fed-basis)[1]

	Crystalline AA level					
	Low			High		
Item, %	Fish meal	Meat and bone meal	Poultry meal	Fish meal	Meat and bone meal	Poultry meal
CP	19.0[2] (21.0)[3]	20.1 (21.4)	19.7 (22.4)	18.9 (19.4)	18.0 (19.4)	18.9 (19.4)
Lys	1.24 (1.43)	1.18 (1.45)	1.20 (1.46)	1.15 (1.42)	1.24 (1.43)	1.18 (1.43)
Ile	0.82 (0.88)	0.78 (0.84)	0.87 (0.90)	0.69 (0.80)	0.72 (0.79)	0.73 (0.79)
Leu	1.55 (1.80)	1.58 (1.76)	1.58 (1.84)	1.49 (1.66)	1.50 (1.65)	1.52 (1.66)
Met	0.38 (0.49)	0.43 (0.50)	0.41 (0.49)	0.45 (0.50)	0.43 (0.50)	0.38 (0.50)
Met + Cys	0.59 (0.83)	0.61 (0.85)	0.66 (0.85)	0.67 (0.83)	0.65 (0.83)	0.62 (0.83)
Thr	0.77 (0.92)	0.76 (0.93)	0.80 (0.95)	0.77 (0.91)	0.76 (0.92)	0.82 (0.92)
Trp	0.28 (0.25)	0.31 (0.24)	0.26 (0.25)	0.25 (0.24)	0.27 (0.24)	0.26 (0.24)
Val	0.92 (0.99)	0.91 (0.99)	0.96 (1.02)	0.90 (0.96)	0.84 (0.97)	0.89 (0.96)

[1]A total of 282 nursery pigs (PIC TR4 × 1050) were used in a 28-d trial to evaluate the effects of replacing high amounts of fish meal, meat and bone meal, and poultry meal with crystalline AA on growth performance.

[2]A representative sample of each diet was collected and analyzed for amino acid composition.

[3]Values in parentheses indicate formulated values.

Table 3.15 Comparison of replacing different specialty protein sources with crystalline amino acids on growth performance in nursery pigs (Exp. 5)[1,2]

	Crystalline AA level[3,4]								
	Low			High				Probability, $P <$	
	Fish Meal	Meat and Bone Meal	Poultry Meal	Fish Meal	Meat and Bone Meal	Poultry Meal	SEM	Protein Source	Low AA vs high AA
d 0 to 14									
ADG, g	243	224	236	258	247	260	11.59	0.19	0.04
ADFI, g	366	348	366	381	370	382	14.35	0.29	0.14
G:F	0.665	0.644	0.645	0.678	0.669	0.681	0.020	0.47	0.14
d 14 to 28									
ADG, g	520	508	515	518	480	515	14.18	0.09[5]	0.42
ADFI, g	831	827	859	825	801	844	21.06	0.09[6]	0.38
G:F	0.626	0.614	0.599	0.628	0.599	0.611	0.009	0.03[7]	0.98
d 0 to 28									
ADG, g	381	366	375	388	363	387	11.02	0.08[8]	0.57
ADFI, g	598	587	612	603	585	611	16.42	0.13	0.96
G:F	0.638	0.623	0.613	0.644	0.621	0.633	0.010	0.08[9]	0.35
BW, kg									
d 0	6.59	6.59	6.59	6.60	6.59	6.59	0.059	0.99	1.00
d 14	10.00	9.74	9.90	10.21	10.04	10.07	0.176	0.58	0.46
d 28	17.28	16.83	17.12	17.45	16.75	17.15	0.328	0.39	0.94

[1] A total of 282 nursery pigs (PIC TR4 × 1050) were used in a 28-d growth trial to evaluate the effects of replacing high amounts of specialty protein sources with crystalline AA on growth performance of nursery pigs. Values represent the means of 7 pens per treatment.
[2] Treatment diets were fed from d 0 to 14 and a common diet fed from d 14 to 28.
[3] Pigs were fed either a low or a high crystalline AA level.
[4] Pigs were fed either fish meal, meat and bone meal, or poultry meal.
[5] Effect of fish meal vs. meat and bone meal ($P < 0.10$).
[6] Effect of poultry meal vs. meat and bone meal ($P < 0.10$).
[7] Effect of fish meal vs. meat and bone meal or poultry meal ($P < 0.05$).
[8] Effect of fish meal vs. meat and bone meal ($P < 0.10$).
[9] Effect of fish meal vs. poultry meal ($P < 0.10$).