EFFECT OF PHASE TWO DIETS WITH DIFFERENT PROTEIN SOURCES AND LYSINE LEVELS ON PERFORMANCE OF NURSERY PIGS

By

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FORMAT OF THESIS

This thesis is presented in the Journal of Animal Science style and format allowing for independent chapters to be suitable for submission to scientific journals. Two papers have been prepared from research data collected at Oklahoma State University to partially fulfill the requirements for a Masters of Science degree. Each paper is complete in itself containing an abstract, introduction, materials and methods, results, implications, and literature cited section.

CHAPTER I

INTRODUCTION

In the last six years there has been a tremendous increase in Oklahoma's swine production. Since 55 to 65% of the total cost of swine production is attributed to feed costs, nutrition is of utmost importance. In this thesis two experiments are described regarding nutrition of early weaned pigs. Because Oklahoma is a major producer of hard red winter wheat, an experiment was conducted to determine the optimum level of lysine in diets for phase 2 nursery pigs. The second experiment was conducted to determine the effect of decreasing protein levels by supplementing the diets with crystalline amino acids. A positive effect of this can be that the total nitrogen excretion from pigs can be reduced, and thus less nitrogen excreted in the environment.

CHAPTER II

REVIEW OF LITERATURE

Many studies have been conducted to determine the lysine requirement for weaned pigs in the range from 5 to 20 kg. Since the recommendations for lysine levels made by the NRC (1988), many changes have occurred, such as the use of the ideal protein concept and an increase in the use of crystalline amino acids. This chapter summarizes studies which attempted to determine the lysine requirement for weaned pigs with corn-soybean based diets and wheat-based diets. The concept of ideal protein and the factors which influence differences in performance between diets based on natural amino acids and diets with high levels of crystalline amino acids will be discussed. The factors to be reviewed are: feeding frequency, acid-base homeostatis, ratio of essential and non-essential amino acids, and the rate of amino acid and peptide absorption. This chapter will be concluded with a review of studies measuring blood urea nitrogen, since it can be an indication of protein intake above the requirement.

After weaning at 28 days, a three phase feeding program is often used. The first phase is from weaning until 10 days postweaning, the second phase is from 10 days to 24 days postweaning, and the third phase is usually from 24 days to 42 days postweaning. But currently weaning at 21 days or less is more prevalent, which is referred to as early weaning. Thus if one compares different papers it can be confusing concerning which diet should be used for a certain phase. Perhaps, it would be better to use a weight range instead of a specific time interval.

Another factor which can be confusing when comparing different papers, are the levels of amino acids based on total amino acid values or on ileal amino acid values.

Ileal Digestibility

Digestibility measures the portion of a feedstuff that disappears from the digestive tract and thus is absorped by the pig. Two methods are used to express the digestibility: ileal digestibility and fecal digestibility. Digestibilities determined near the end of the small intestine are called ileal digestibility. Digestibilities determined over the total gastric tract are called total track or fecal digestibility. Ileal digestibility values are more accurate, than the fecal digestibility values, because it does not consider the synthesis and destruction of amino acids in the large intestine (Borggreve, 1994). In general, amino acid degradation in the lower gut is greater than amino acid synthesis. So in most cases ileal digestibility of amino acids are higher than fecal digestibilities (Lenis, 1992). Since there is no amino acid absorption in the large intestine, ileal digestiblity is preferred (Lenis, 1996).

For ileal digestibility there are two methods: apparent ileal digestibility (AID) or real ileal digestibility (RID) (Jondreville, 1994).

$$\text{AID of amino acids (aa)} = \frac{\text{aa ingested} - \text{aa excreted}}{\text{aa ingested}} * 100$$

$$\text{RID aa} = \frac{\text{aa ingested} - (\text{aa excreted} - \text{endogenous aa excreted})}{\text{aa ingested}} * 100$$

Real ileal digestibility is the best way to express protein and amino acid digestibility, but for practical reasons, apparent digestibility is more useful, because it is too difficult to measure endogenous amino acid output precisely (Lenis, 1992).

In this literature review, apparent ileal digestibility will be routinely used, but when other digestibility measures were used, it will be indicated.

Lysine

Lysine has been considered for many years to be the first limiting amino acid in typical corn-soybean meal based diets for pigs. The limiting amino acids are lysine, tryptophan, threonine and methionine as shown by Corley and Easter (1980, 1983) in diets fed to pigs from 4 to 8 wks of age. Lately more attention is given to the optimum ratios between amino acids. Because lysine is the first limiting amino acid in swine diets, it is used as the basis for the optimum ratios between amino acids. In the literature several levels of lysine are recommended for growing pigs. The total lysine levels recommended by NRC (1988) are 1.15 % for pigs with a live weight from 5 to 10 kg and 0.95% lysine for pigs with a live weight from 10 to 20 kg. But in the swine industry, the percentage lysine fed are usually greater, because studies suggests that the recommended lysine levels of the NRC (1988) are too low.

Rose et al. (1994) found, in an experiment conducted at Oklahoma State University, that the level recommended for phase 2 pigs weaned at 3 to 4 wks of age was at least 1.40% total lysine. The diets were based on corn and soybean meal and were fed to pigs from 10 to 26 kg. Aherne and Nielsen (1983) found a total lysine requirement of approximately 1.15% and a protein requirement of 20% protein for pigs with a liveweight from 7-19 kg. The diet fed was a barley-wheat-soybean meal based diet. Most studies used corn-soybean meal diets, but other ingredients can also be used. Often it is determined by the ingredients available at a reasonable price. Oklahoma is a large producer of hard red winter wheat, therefore studies were conducted regarding the lysine levels of wheat-based diets.

Wheat

Grains are an important source of carbohydrates and energy in swine diets. The most important grain used in swine diets is corn, but other important sources are sorghum, barley, oats and wheat. Wheat and wheat products are extensively used for human consumption, however, there have been periods in recent years when wheat has been competitively priced with other cereal grains, justifying its use in swine diets. When wheat is competitively priced with other cereal grains, it becomes especially attractive to Oklahoma pork producers since Oklahoma is a major wheat producing state. Wheat production in the state ranges from 110 to 200 million bushels per year (Oklahoma Department of Agriculture, 1995).

Rodriguez and Young (1981) conducted an experiment with pigs weaned at 7 days, to study the utilization of corn or wheat as replacement ingredients for milk products. The average weight of the pigs was 2.77 kg and the diets fed contained 38 % whey, or 30% corn, or 30% wheat replacing whey on a pound to pound basis. No differences in performance, ADG and ADFI were observed between the different treatment groups. No difference was found for protein digestibility from whey, wheat or corn, demonstrating that pigs could effectively use either wheat or corn as a substitute for whey at a level of 30% of the diet.

de Rodas et al. (1997) conducted an experiment with early weaned pigs (19±2 d of age) to examine the efficacy of hard red wheat based diets during phase 2 (day 10 to 38 postweaning). Wheat replaced 50 or 100% of the corn and comprised 30% or 60% of the diet, respectively. Performance was superior in pigs fed the wheat-based diets when compared to those fed the corn-soybean meal control diet. The lysine level of all three diets was 1.4% total lysine. There was a linear increase in ADG and feed efficiency with increasing wheat in the diet.

In an experiment conducted by Bruneau and Chavez (1995) with weaned pigs at 21 d of age (8.06±1.06 kg live weight) until 34 days of age the preference for cereal grains was determined. The diet contained 30% basal mix and 70% grain. The cereal grains used were yellow dent corn (8.7% crude protein), hard winter wheat (15.8% crude protein), oats (11.8% crude protein) and barley (12.7% crude protein). The pigs could choose between two diets, for example corn and wheat, and the preference was calculated based on consumption. All possibilities (6 in total) were tested twice. The conclusion was that wheat was the most preferred cereal grain followed by corn, barley and oats. The lysine level was not reported.

The feeding value of cereal grains for pigs fed from 9 kg to 25 kg was compared in a study done by Grosjean and Gatel (1987). The diets contained corn, wheat or barley and the type of wheat not reported. The cereal grain formed up to 60-70% of each diet, and each diet was fed ad libitum. The total lysine level was 1.19%. Performance was slightly improved for the pigs fed wheat as compared to corn suggesting that wheat was a comparable energy source with corn.

Hanrahan and O´Grady (1984) conducted an experiment with weaned pigs (10-25 kg) with wheat compared to a barley-maize combination in the diet. The levels of wheat were 0, 22, 44 and 66% of the diet. The lysine levels were 1.28, 1.31, 1.34 and 1.30, respectively. Pellet quality of diets improved with greater wheat content. Feed efficiency improved with increasing levels of wheat, but this was probably related to the higher energy content of the wheat diets. The conclusion was that wheat could replace a mixture of barley and maize with little effect on performance.

In research conducted by Magowan and Aherne (1988), the nutritional value of soft white spring wheat was compared with hard spring wheat in starter diets for weanling pigs. The pigs were 24 days old and weighing 7.23 kg at study initiation. The diets were formulated to contain 20% protein, 1.15% lysine and a gross energy level of 16 MJ per kg of diet. There was no significant difference between the use of hard red spring wheat or soft white spring wheat, but it was mentioned that the soft white spring wheat would require more soybean meal to formulate a diet with a 20% protein level.

Seerley et al. (1988) reported no difference in ADG or feed efficiency with weaned pigs (28 d of age and weighing 8.5 kg) fed finely ground wheat (soft red winter) or corn in a diet formulated to contain 1.18% lysine. But the pigs fed the finely ground wheat diet had a significantly improved feed intake than those fed the corn diet. Particle size of wheat in nursery pigs had no influence on daily gains.

A method to reduce supplemented protein is to use a grain which is higher in essential amino acids than corn. The amino acid values of hard red winter wheat, with the exception of leucine, are higher than those of dent yellow corn (NRC, 1988). There are several experiments with wheat as one of the main ingredients in the experimental diets.

In research conducted by Batterham et al. (1988), diets were used with a high level of grains (795g/kg). It was a 7 x 2 factorial design (7 cereal grains x 2 sexes) with six forms of triticale compared to wheat. The weight of the pigs was from 20 to 50 kg. No significant differences in ADG, G:F and lean content of ham were found between the pigs fed triticale or wheat. Giles et al. (1987) conducted an experiment with 8 levels of dietary lysine, 2 sexes and 2 grains (barley and wheat) in a 8 x 2 x 2 factorial experiment with pigs from 20 to 50 kg live weight. The wheat based diet contained 78.5% wheat and 14% SBM. Maximum daily gain with the wheat based diets occurred with a lysine concentration of 11.2 g/kg for males and 13.1 g/kg for females. Maximum daily gain with the barley based diets occurred with a lysine concentration of 14g/kg.

Producers prefer corn-wheat mixed or corn diets, because wheat diets tend to cause bridging in feeders and pens are hard to clean (Seerley, 1991).

Diets containing wheat require reduced supplementation of amino acids to meet requirements compared with corn diets. Since the eighties with the increasing awareness for the environment, crystalline amino acids have been used to reduce nitrogen excretion. With the arrival of crystalline amino acids, the concept of formulating diets changed from formulation based on protein to formulation were ratios of amino acids are optimized. This concept is commonly referred to as the ideal protein concept.

Ideal Protein

Diets have been developed based on the ideal protein concept to maximize pig performance. An ideal protein diet optimizes protein retention with a minimum of nitrogen excretion. In a study conducted by Chung and Baker (1992) four diets were compared based on ideal amino acid patterns from ARC (1981), NRC (1988), Wang and Fuller (1989) and Chung and Baker (1991). The result of that study was that pigs fed the amino acid pattern from Chung and Baker performed superior to the pigs fed the other diets. The optimum pattern of indispensable AA used in comparison of the four diets contained (grams of AA/100 g lysine): lysine (100), methionine + cysteine (60), threonine (65), tryptophan (18), phenylalanine + tyrosine (95), leusine (100), isoleucine (60) valine (68), arginine (42), and histidine (32). The total lysine level was 1.20%.

In earlier experiments Chung and Baker (1991) reported a superior performance of pigs fed a purified diet compared with a positive control corn-soybean meal-dried whey diet. The factors considered when formulating the purified diet were: 1. a proper balance between indispensable and dispensable amino acids; 2. adding NaHCO3 to buffer acidity; 3. use of glutamate-glycine-proline mixture as source for the dispensable amino acids; 4. improving palatibility by inclusion of 15% lactose and 15% sucrose; 5. include enough selenium.

Several factors are important for optimizing the protein nutrition (Knabe, 1996). Computer simulation models which take into account, sex, lean deposition rate, factorial method and apparent ileal digestibility can be used to make better estimations for amino acid requirements of the pigs in various stages of production. Sex and lean deposition rate because it influences the protein deposition. The factorial method is preferred, because it differentiates between protein used for maintenance and for production. Last but not least the use of crystalline amino acids can help in a reduction of nitrogen excretion in the environment.

With the increasing awareness for the environment, more experiments were conducted with increasing amounts of crystalline amino acids and less protein in diets. In most of these experiments, the performance of pigs fed diets with high levels of crystalline amino acids are not equal to those of pigs fed diets based on natural amino acid sources. Factors which influence in the differences between diets based on natural amino acids and low protein diets supplemented with crystalline amino acids are imbalance of amino acids, feeding frequency, acid-base homeostatis, balance between essential and non-essential amino acids and the difference in absorption between amino acids and peptides.

Imbalance of Amino Acids

Currently many diets are based on the ideal protein concept, therefore problems with imbalance are less likely to occur. However, lysine is an amino acid which is known as heat inlabile (Baker, 1994) and processing of feed may destroy lysine. In research reported by Davis (1996) with diets containing high levels of crystalline lysine, the analyzed lysine levels were much lower than the calculated lysine levels. The reason for this effect was not clear, but it could be a result of the Maillard reaction. Which is heat changing the chemical structure of the amino acid. Chung and Baker (1991) reported that lactose can react in Maillard linkages with free amino acids.

Feeding Frequency

Feeding frequency has an influence on the use of low protein diets supplemented with crystalline amino acids (Brudevold and Southern (1994), Batterham (1974), Batterham and O'Neill (1978)). In research conducted by Batterham (1974) with growing pigs, the conclusion was that supplementation of L-lysine to diets fed once a day or by a frequent feeding regimen, the growth responses in the once a day feeding regimen were only 69% of those achieved with the frequent feeding regimen. In a later experiment by

Batterham and O'Neill (1978), the growth response was only 67% with the once a day feeding compared with the frequent feeding regimen. The explanation for the difference in performance was that with a frequent feeding regimen, the amino acid supply at the sites of absorption and metabolism are more balanced which results in a more efficient use of the amino acids. Baker (1994) suggested that if using crystalline amino acids in practical diets, the feeding frequency should be at least twice a day.

Acid-Base Homeostatis

The balance between acids and bases in the diet is called the acid-base homeostatis and is important for the proton concentration which is involved in the transport processes of amino acid absorption. When using high amounts of crystalline amino acids it is important to keep in mind that the acid-base homeostatis can be changed. When oxidation of protein occurs, it is a net contribution of acid (Patience, 1990). Three possible causes for problems with diets high in crystalline amino acids are:

1) synthetic amino acids supplied as Cl- salts; especially lysine

2) sulfur amino acids when present in excess; methionine and cysteine

3) decrease of K, because the amount of SBM in the diet will be decreased.

Supplement diets high in crystalline amino acids with NaHCO3 to avoid complications with the acid-base homeostatis was recommended by Patience (1990). However, Brudevold and Southern (1994) found no effect on ADG, ADFI or feed efficiency when NaHCO3 was added to a diet with high levels of crystalline amino acids.

Essential and Non-Essential Amino Acids

Reducing the non-essential amino acids in the diet improved the efficiency of N utilization, because of the recycling of N (Lenis et al. (1994)). One aspect which has to be watched with the composition of low protein diets supplemented with crystalline amino acids, is the balance between the essential amino acids (eAA) and the non-essential amino acids (neAA). Fickler et al. (1994) formulated a diet to see if performance in pigs fed a crystalline amino acids based on the ideal protein concept from Chung and Baker (1991) would equal that observed in pigs fed a traditional diet. Performance decreased and they suggested an increase in the level of dispensable amino acids should lead to the same performance.

Omission of arginine, glutamic acid, and proline in a chemically defined diet affected N accretion by 50%, 6% and 8%, respectively (Roth et al. (1994)). Thus a chemically defined diet for piglets requires a certain amount of arginine, glutamic acid, and proline in the diet for optimum N accretion.

To determine the influence of proline on N-balance of piglets (15 kg live weight) an experiment was conducted by Kirchgessner (1995). For maximum N utilization a proline level between 0.7 and 1.4% is required. The same research group reported that at least 0.55% of arginine is needed in a chemically defined diet for piglets (15 kg live weight) for optimum N utilization and retention (Fickler et al. (1995)). The recommended amount for glutamic acid in diets for weaned pigs is 2.0% (Roth et al. (1995)).

For the absorption of amino acids in the intestine, there are several systems available. Webb (1990) described in a review paper regarding intestinal absorption of protein hydrolysis products, systems of diffusion, facilitated diffusion and active transport (Na^+

dependent) for the uptake of amino acids. Diffusion takes the biggest part of the uptake. There is a difference in speed of intake between essential and non-essential amino acids (Adibi et al., 1967).

Webb (1990) concluded in a review paper; 1) that amino acids can be absorbed in the form of di- and tri-peptides; 2) amino acid composition of the peptide has an influence on absorption; 3) peptides compete with other peptides regarding absorption; 4) the driving force behind the peptide absorption is a proton gradient; 5) all peptides entering enterocytes are hydrolysed to single amino acids by cytoplasmic peptidases. In a study by Vazquez et al. (1985) with humans, it was found that starvation decreases amino acid absorption, but that absorption of peptide hydrolysis was improved. Even after 1 week of starvation amino acid absorption from peptides was maintained. Possibly, amino acid absorption from peptides takes less energy, and this could mean that adding free amino acids to the pig diet requires more energy.

Blood Urea Nitrogen and Creatinine

Urea is the major end product of protein nitrogen metabolism. The level of urea is an indication of the level of excess nitrogen available for metabolism. The level of urea can be measured in the urine and in the blood. Blood urea nitrogen (BUN) values increases when the protein content in the diet increases (Eggum, 1970). BUN values increases when there is amino acid imbalance in the diet. When a diet is fed which is deficient in one amino acid, the BUN values are greater compared with a diet fed where the deficient amino acid is added (Brown and Cline, 1974). The BUN values are relatively constant when the pigs are fed in a system with free access to feed (Cai et al., 1994). So sampling time does not have an influence in systems with ad libitum feed access.

Concentration of BUN are much lower when diets are based on the "ideal protein" concept (Lopez et al., 1994; Davis, 1996). In an experiment conducted by Kerr and Easter (1995), the urea nitrogen values for a low protein diet supplemented with lysine, tryptophan and threonine were much lower than the values for the high protein diet. Decreased urea nitrogen concentrations with increasing energy intake was an indication for improved N utilization for protein accretion (Cai et al., 1995).

Serum creatinine is a waste product formed by the spontaneous dehydration of body creatine. Most of the body creatine is found in muscle tissue where it is present as creatine phosphate and serves as a high-energy storage reservoir for conversion to adenosine triphophosphate. The rate of creatinine formation is fairly constant with about 2 percent of the body creatine being converted to creatinine every 24 hours. The level of creatinine is an indication of muscle breakdown.

Conclusion

To meet the requirement of pigs as best as possible, diets should be formulated based on ileal digestibility values and ideal protein concept. The optimum lysine level for pigs on corn-soybean meal based diets has been extensively studied, but for diets based on wheat-soybean meal only limited information regarding the optimum level of lysine is available. In several experiments there are differences in the performance of pigs fed diets based on natural amino acid sources and pigs fed diets with high levels of crystalline amino acids. Several factors should be considered when experiments conducted with diets containing high levels of crystalline amino acids. These factors are ad libitum feed access, acid-base homeostatis of the diet, ratio between essential and non-essential amino acids and levels of the non-essential amino acids; proline, arginine and glutamic acid. Blood urea nitrogen values can be a good indication of the level of excess nitrogen available for metabolism. Creatinine levels are a good indication for the muscle breakdown.

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CHAPTER III

LYSINE REQUIREMENT OF PHASE TWO NURSERY PIGS FED HARD RED WINTER WHEAT BASED DIETS

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ABSTRACT

Two experiments involving 120 pigs (21±3 d of age; 6.3 kg BW) were conducted to determine the dietary lysine requirement to maximize growth performance of phase two (day 10 to 38 post weaning) nursery pigs fed a hard red winter wheat (Karl variety)-soybean meal (SBM) diet. Pigs were blocked based on initial BW and penned in groups of five. All pigs were fed a common phase 1 diet containing 1.50% lysine for the first 10 days (Exp. 1) or 8 days (Exp. 2) following weaning. After phase 1, pigs (7.7 kg BW) were assigned to one of four dietary treatments (6 pens/treatment). Dietary treatments were 1.30, 1.40, 1.50 and 1.60% total lysine. Wheat (Exp. 1) and corn starch and sucrose (Exp. 2) were replaced by SBM to provide additional lysine levels. Experimental diets were fed for 28 days (phase 2) with gain and efficiency of gain obtained weekly. From d 0 to 7 (phase 2), ADG and G/F increased linearly ($P < .01$) with increasing dietary lysine. Increasing dietary lysine improved ADG and G/F (linear, $P < .01$; quadratic, $P < .05$, respectively) from d 7 to 14 with a maximum G/F observed at 1.50% lysine. During d 14

to 28, ADG was improved (linear, $P < .07$) with increasing dietary lysine. Feed intake was not affected by treatment during any phase of the study. Blood urea nitrogen (BUN) concentrations (day 14) increased (linear, $P < .01$) with increasing dietary lysine levels. These results indicate that the dietary lysine requirement for maximum performance of phase 2 nursery pigs fed a hard red winter wheat-SBM diet is at least 1.60% in week 1 with some indication of a reduction in requirement after d 7.

INTRODUCTION

Lysine has been considered for many years the first limiting amino acid in typical corn-soybean meal diets fed to swine. The lysine requirement of early weaned pigs (10 to 20 kg) fed corn-soybean meal diets has a range of estimates from .90 to 1.40% (Lin and Jensen, 1985; Martinez and Knabe, 1990, and Rose et al., 1994). The NRC (1988) lists the lysine requirement as 1.15% for 5 to 10 kg pigs and .95% for 10 to 20 kg pigs, which is generally considered too low by the swine industry. Research to determine the lysine requirement of early-weaned pigs fed a wheat-soybean meal diet is very limited. Campbell (1978) reported that optimum performance was obtained on 5.5 to 20 and 11.8 to 20 kg pigs with dietary lysine levels of 1.08 and .90%, respectively, in wheat based diets. However, the class of wheat was not identified. Aherne and Nielsen (1983) reported that 6.8 to 19.1 kg weanling pigs had a dietary lysine requirement of 1.15% when fed a wheat-barley based diet. Again the class of wheat or barley was not identified. Oklahoma is a major producer of hard red winter wheat with an annual yield of 3 to 5.4 million tons (Oklahoma Department of Agriculture, 1995). Often wheat is competitively priced with yellow corn which suggests its use in swine diets as the primary energy source. In addition, a recent study by de Rodas et al. (1997) indicated that Karl hard red winter wheat could be an excellent substitute for corn in phase two nursery swine diets.

The objective of this study was to determine the lysine requirements of early-weaned pigs fed a Karl hard red winter wheat based diet during phase two of the nursery period.

MATERIALS AND METHODS

Two trials, involving a total of 120 pigs (60 pigs in each of the two trials), were conducted to determine the lysine requirement of phase 2 (day 10 to 38 post weaning) nursery pigs fed a hard red winter wheat (Karl variety)-soybean meal (SBM) diet. Pigs were weaned at 21±3 days of age with an average weight of 6.3 kg. At weaning, pigs were allotted into three groups (blocks) based on initial BW. Pigs within each weight block and trial were allotted into four equal subgroups (five pigs per pen) with stratification based on litter and sex. During the first 10 d (Exp. 1) or 8 d (Exp. 2) following weaning, all pigs were fed a common phase 1 diet (Table 3.2) containing 1.50% lysine, .93 % Ca and .84% P. On d 10 (Exp. 1) or d 8 (Exp. 2) post weaning, pigs were stratified within each block to obtain similar weights per pen. During d 0 to 8 or 10 postweaning, ADG across pens was consistent and reallocation of pigs to equalize mean weight per pen was minimal. Dietary treatments were randomly assigned to pens within weight group and trial (3 pens/treatment/trial) for the phase 2 period. Analyzed amino acid values of wheat samples were used for formulation of phase 2 diets (Table 3.1). Phase 2 diets were formulated by substituting SBM for wheat (Exp. 1, Table 3.2) or corn starch and sucrose (Exp. 2, Table 3.3) to obtain lysine levels of 1.30, 1.40, 1.50 and 1.60% in the diet. All four diets were formulated to contain .90% Ca and .75% P, to exceed the NRC (1988) standards for all nutrients and based on the ideal amino acid ratios according to Chung and Baker (1992). Experimental diets were fed for 28 d (phase 2). Samples of wheat and the four diets were analyzed for amino acids (Table 3.1, 3.4 and 3.5) by the Experimental Station Chemical Laboratories, University of Missouri, Columbia. In addition, samples were analyzed for moisture and crude protein (AOAC, 1990).

The temperature of the nursery rooms was maintained at 30°C during the first week and then decreased 1°C per week. Pigs had ad libitum access to one nipple waterer and a four-hole feeder. Body weight and feed intake were determined at the end of phase 1 and weekly thereafter to evaluate average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (G/F). Blood samples were taken via anterior vena cava puncture on day 14 of phase 2 (Exp. 2) and serum was analyzed for urea N concentration (BUN) using the Roche® Reagent for BUN.

Data were analyzed as a randomized complete block design with pen as the experimental unit. Blocks were based on initial body weight. Analysis of variance was conducted using the GLM procedure of SAS (1988). Orthogonal polynomials were used to test for linear, quadratic and cubic effects of lysine levels on performance and BUN.

RESULTS

The calculated and analyzed amino acid composition of phase 2 diets are shown in Tables 3.4 and 3.5. The analyzed amino acid values are very close to the calculated values. Average daily gain, ADFI and G/F during the phase 1 adjustment period following weaning were 181 g/d, 222 g/d and .82, respectively.

During phase 2, there was no trial x treatment interaction, therefore data from both trials were combined. From d 0 to 7 of phase 2 (after pigs were switched to their experimental diets), ADG and G/F increased linearly ($P < .01$) as dietary lysine level increased (table 3.6). Pigs fed 1.60% lysine grew 25% faster and were 20% more efficient than pigs fed 1.30% lysine. Average daily feed intake was not affected by dietary treatments.

During d 7 to 14 of phase 2, increasing dietary lysine improved ADG and G/F (linear, $P < .01$; quadratic, $P<.05$, respectively) with a maximum observed in G/F at 1.50% lysine. Pigs fed 1.50% lysine grew 18% faster and were 33% more efficient than pigs fed 1.30% lysine. Feed intake was again not affected by dietary treatments.

During d 14 to 28 of phase 2, ADG increased linearly ($P<.07$) with increasing dietary lysine. Feed intake and G/F, however, were similar among dietary treatments. During the overall 28-d phase 2 period, there was linear growth ($P < .01$) and G/F ($P < .01$) responses to increasing dietary lysine even though there were no apparent additional responses in G/F above 1.50% lysine. Pigs fed the lysine level of 1.60% grew 13% faster and were 12% more efficient than pigs fed 1.30% lysine. Feed intake was not affected by dietary treatment. Blood urea nitrogen concentrations (d 14) increased (linear, $P< .01$) as dietary lysine level increased.

DISCUSSION

Karl hard red winter wheat is a good alternative to corn in phase 2 nursery swine diets (de Rodas et al., 1997). It serves as a source of energy and protein. In addition, it contains higher levels of crude protein and most limiting amino acids than corn (Table 3.1). Lysine has been considered for many years the first limiting amino acid in typical corn-soybean meal diets fed to swine. The NRC (1988) list the lysine requirement as 1.15% for 5 to 10 kg pigs and .95% for 10 to 20 kg pigs. Research to determine the lysine requirement of early-weaned pigs fed a wheat-soybean meal diet is very limited. Campbell (1978) observed optimum performance in 5 to 20 kg pigs fed wheat based diets containing 1.08% lysine. Aherne and Nielsen (1983), on the other hand, indicated that 7 to 19 kg weanling pigs had a dietary lysine requirement of 1.15% when fed a wheat-barley based diet. In our study, however, increasing dietary lysine from 1.30 to 1.60% resulted in a linear increase in ADG and G/F during the first two wk of the phase 2 (d 10 to 24 post weaning; 7.7 to 10.4 kg BW) postweaning period, suggesting that phase 2 nursery pigs need much higher lysine requirements than levels recommended by the NRC (1988). Rose et al. (1994) reported a linear increase in growth performance of phase 2 nursery pigs (10 kg BW) with increasing lysine levels in a corn-soybean meal diet from .95 to 1.40% in .15% increments of total lysine. Similarly, Davis et al. (1996) observed a linear increase in ADG and G/F ratio in phase 1 nursery pigs (6 kg BW) with increasing lysine levels in a high nutrient dense diet from 1.15 to 1.60% in .15% increments of total lysine.

Concentrations of BUN increased linearly with increasing dietary protein. These results are consistent with those reported by Owen et al. (1995) and Chung et al. (1996) who found a linear increase in BUN with increasing dietary lysine from 1.40 to 1.80% and from 1.30 to 1.75%, respectively.

With the current environmental concern over nitrogen excretion from modern swine facilities, interest has surfaced in the use of crystalline amino acids in the formulation of swine diets. This would result in a reduction of nitrogen excretion by decreasing the amount of excess amino acids that occur when balancing for the most limiting amino acid. Lysine and threonine are the first two limiting amino acids for growing-finishing pigs fed wheat based diets (Myer et al., 1996). Therefore, supplementation with crystalline lysine could substantially reduce or replace supplemental protein (soybean meal) when hard red winter wheat is used as the primary feed grain in phase 2 nursery pig diets. In addition, Oklahoma is a major producer of hard red winter wheat with an annual yield of 110 to 200 million bushels (Oklahoma Department of Agriculture, 1995) and often wheat is competitively priced with yellow corn which suggests its use in swine diets as the primary energy source.

In general, the results of this study confirm that wheat is an excellent grain source for phase 2 nursery pigs, and that optimum performance can be achieved when pigs are fed 1.60% lysine during the first wk of phase 2, with some indication of a slight reduction in requirement after day 7.

IMPLICATIONS

The results of this study indicate that faster growth and a higher gain to feed ratio can be achieved in 7.6 to 10 kg pigs if wheat-soybean meal based diets contain a total lysine level of 1.60%. After that, the total lysine content of the diets should be at least 1.40% for pigs in the range from 10 to 22 kg. In addition, more research should be conducted to determine the limits of substitution of crystalline lysine for natural lysine sources to reduce nitrogen excretion.

Table 3.1 Comparison of yellow dent corn, and hard red winter wheat.

	Corn[a]	Wheat[b]	Wheat
Composition, %	NRC	NRC	Analyzed[c]
Dry matter	88	88	88.67[d]
Crude protein	8.5	12.6	15.23
Lysine	.25	.40	.42
Tryptophan	.09	.17	.18
Threonine	.36	.37	.45
Methionine	.18	.22	.25
Cysteine	.22	.30	.38
Valine	.48	.58	.65
Isoleucine	.35	.53	.49
Phenylalanine	.46	.71	.75
Tyrosine	.38	.46	.44
Leucine	1.19	.87	1.06
Arginine	.43	.65	.74
Histidine	.27	.30	.36

[a] Yellow dent corn listed in NRC (1988).
[b] Hard red winter wheat listed in NRC (1988).
[c] Hard red winter wheat analyzed by Experimental Station Chemical Laboratories, University of Missouri, Columbia.
[d] Analyzed for moisture (AOAC, 1990)

Table 3.2 Composition of experimental diets comparing different lysine levels for experiment 1[a].

	Phase 1	Phase 2			
		Lysine, %			
Ingredient, %		1.30	1.40	1.50	1.60
Corn, yellow dent	38.06	-	-	-	-
Wheat, hard, red winter	-	70.00	66.43	62.595	59.125
Soybean meal, 48% CP	10.00	20.00	23.625	27.50	31.00
Fishmeal, menhaden	8.00	4.00	4.00	4.00	4.00
AP-301[b]	1.50	2.75	2.75	2.75	2.75
AP-920[c]	3.50	-	-	-	-
Whey, dehydrated	10.00	-	-	-	-
Lactose, 97%	11.36	-	-	-	-
Steam rolled oats	10.00	-	-	-	-
Soybean oil	4.00	-	-	-	-
Neo-terramycin 10/5[d]	1.00	-	-	-	-
Tylan 40-sulfa[e]	-	.125	.125	.125	.125
Sodium Chloride	.20	.30	.30	.30	.30
Calcium Carbonate	-	.50	.52	.58	.60
$CuSO_4.5H_2O$	.07	.05	.05	.05	.05
Micro curb	-	.10	.10	.10	.10
Dicalcium Phosphate	1.45	1.625	1.55	1.45	1.40
Vit./Min. premix[f]	.38	.25	.25	.25	.25
Zinc Oxide	-	.30	.30	.30	.30
Ethoxiquin	.03	-	-	-	-
Lysine, HCl	.26	-	-	-	-
DL-Methionine	.09	-	-	-	-
Berry flavor	.10	-	-	-	-

[a] As fed basis. Diets were formulated to contain 1.50% lysine, .93% Ca, and .84% P in Phase 1; and .90% Ca, and .75% P in Phase 2, and to exceed the NRC (1988) standards for all nutrients.

[b] Blood meal source, American Protein Corp., Ames, IA.

[c] Plasma protein source, American Protein Corp., Ames, IA.

[d] Contained 22 g of neomycin and 11 g of oxytetracline per kg.

[e] Contained 88 g of tylosin and 88 g of sulfamethazine per kg.

[f] Supplied 9,152 IU of vitamin D_3, 40 IU of vitamin E, 7.3 mg of vitamin K_3, 8.8 mg of riboflavin, 62 mg of niacin, 44 mg of d-pantothenic acid, 587 mg of choline, 1.6 mg of biotin, 3.3 mg of pyridoxine, 1 mg of folic acid, 5.5 mg of thiamine, 40 μg of vitamin B_{12}, .2 mg of Se, 70 mg of Mn, 220 mg of Zn, 220 mg of Fe, 22 mg of Cu, and .44 mg of I, and 540 mg of K per kg of feed during Phase 1, and 6,600 IU of vitamin A, 660 IU of vitamin D_3, 12.8 IU of vitamin E, 5.5 mg of vitamin K_3, 5.1 mg of riboflavin, 36.3 mg of niacin, 33 mg of d-pantothenic acid, 343.9 mg of choline, 20 μg of vitamin B_{12}, .2 mg of Se, 40 mg of Mn, 15 mg of Zn, 150 mg of Fe, and .37 mg of I per kg of feed during Phase 2.

Table 3.3 Composition of experimental diets comparing different lysine levels for experiment 2[a].

	Phase 2 diets			
	Lysine, %			
Ingredient, %	1.30	1.40	1.50	1.60
Cornstarch	4.935	3.155	1.575	-
Sucrose	4.93	3.155	1.575	-
Wheat, hard red winter	60.085	60.085	60.085	60.085
Soybean meal, 48% CP	20.00	23.60	26.80	30.00
Fishmeal, menhaden	4.00	4.00	4.00	4.00
AP-301[b]	2.75	2.75	2.75	2.75
Tylan 40-sulfa[c]	.125	.125	.125	.125
Sodium Chloride	.30	.30	.30	.30
Calcium Carbonate	.40	.50	.52	.57
$CuSO_4 .5H_2O$	.05	.05	.05	.05
Micro curb	.10	.10	.10	.10
Diecalcium Phosphate	1.775	1.62	1.54	1.44
Vit. Min. premix[d]	.25	.25	.25	.25
Zinc Oxide	.30	.30	.30	.30
DL-methionine	-	.01	.03	.03

[a] As fed basis. Diets were formulated to contain .90% Ca and .75% P, and to exceed the NRC (1988) standards for all nutrients.

[b] Blood meal source, American Protein Corp., Ames, IA.

[c] Contained 40 g of tylosin and 40 g of sulfamethazine per lb.

[d] Vitamins and minerals met or exceed the NRC (1988) requirements. Supplied 6,600 IU of vitamin A, 660 IU of vitamin D_3, 12.8 IU of vitamin E, 5.5 mg of vitamin K_3, 5.1 mg of riboflavin, 36.3 mg of niacin, 33 mg of d-pantothenic acid, 343.9 mg of choline, 20 μg of vitamin B_{12}, .2 mg of Se, 40 mg of Mn, 15 mg of Zn, 150 mg of Fe, and .37 mg of I per kg of feed during Phase 2.

Table 3.4 Calculated (C) and analyzed (A) composition of the experimental diets of experiment 1[a]

	Phase 2 diets							
	Lysine, %							
	1.30		1.40		1.50		1.60	
Composition	C	A	C	A	C	A	C	A
Crude protein	-	20.87	-	26.36	-	27.3	-	28.53
Lysine	1.30	1.16	1.40	1.38	1.50	1.46	1.60	1.55
Tryptophan	.30	.27	.32	.28	.34	.34	.35	.38
Threonine	.84	.77	.90	.89	.96	.91	1.01	.97
Methionine	.55	.35	.58	.41	.57	.42	.57	.42
Cysteine	.39	.37	.41	.42	.43	.42	.45	.44
Valine	1.22	1.09	1.29	1.24	1.37	1.29	1.43	1.35
Isoleucine	.85	.82	.92	.91	.99	.98	1.05	1.03
Phenylalanine	1.16	1.07	1.23	1.20	1.30	1.25	1.36	1.31
Tyrosine	.70	0.63	.78	.69	.81	.71	.86	.76
Leucine	1.84	1.69	1.94	1.90	2.05	1 99	2.16	2.07
Arginine	1.33	1.27	1.44	1.47	1.55	1.56	1.65	1.63
Histidine	.71	.63	.75	.68	.79	.76	.82	.75

[a] The treatment diets were analyzed by Experimental Station Chemical Laboratories, University of Missouri, Columbia.

Table 3.5 Calculated (C) and analyzed (A) composition of the experimental diets of experiment 2[a]

	Phase 2 diets							
	Lysine, %							
	1.30		1.40		1.50		1.60	
Composition	C	A	C	A	C	A	C	A
Crude protein	23.57	23.25	25.29	25.31	26.83	26.67	28.36	28.10
Lysine	1.30	1.27	1.40	1.38	1.50	1.47	1.60	1.61
Tryptophan	0.28	0.28	0.30	0.32	0.32	0.36	0.33	0.38
Threonine	0.85	0.83	0.92	0.91	0.98	0.95	1.04	1.03
Methionine	0.38	0.39	0.41	0.42	0.45	0.46	0.48	0.47
Cysteine	0.41	0.43	0.43	0.46	0.45	0.50	0.48	0.49
Valine	1.25	1.23	1.33	1.29	1.41	1.38	1.49	1.44
Isoleucine	0.86	0.92	0.94	1.00	1.01	1.09	1.08	1.11
Phenylalanine	1.22	1.21	1.30	1.31	1.38	1.38	1.45	1.47
Tyrosine	0.74	0.73	0.81	0.83	0.86	0.86	0.92	0.92
Leucine	1.92	1.92	2.05	2.04	2.17	2.14	2.28	2.28
Arginine	1.40	1.36	1.52	1.51	1.63	1.62	1.74	1.70
Histidine	1.04	0.71	1.08	0.75	1.12	0.79	1.16	0.86

[a] The treatment diets were analyzed by Experimental Station Chemical Laboratories, University of Missouri, Columbia.

Table 3.6 Performance of pigs fed increasing levels of dietary lysine during phase 2 of the nursery period[a].

	Lysine, %				
Item	1.30	1.40	1.50	1.60	SEM
Day 0 to 7					
ADG, kg[b]	.31	.35	.34	.38	.013
ADFI, kg	.42	.44	.40	.44	.019
G/F[b]	.74	.80	.88	.89	.03
Day 7 to 14					
ADG, kg[b]	.44	.48	.52	.52	.023
ADFI, kg	.67	.66	.66	.68	.028
G/F[bd]	.66	.72	.80	.78	.02
Day 14 to 28					
ADG, kg[c]	.59	.60	.60	.64	.016
ADFI, kg	.95	.89	.93	.96	.030
G/F	.63	.68	.65	.67	.02
Day 0 to 28					
ADG, kg[b]	.48	.51	.52	.55	.012
ADFI, kg	.74	.72	.73	.76	.022
G/F[b]	.67	.72	.74	.75	.01
d 14 BUN, mg/dl[b]	13.89	16.34	16.94	18.60	.58

[a] Data are means of six pens of five pigs each. Pigs averaged 7.66 and 22.04 kg at initiation and termination, respectively.

[b] Linear effect of increasing dietary lysine ($P<.01$).

[c] Linear effect of increasing dietary lysine ($P<.07$).

[d] Quadratic effect of increasing dietary lysine ($P<.05$).

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CHAPTER IV

EFFICACY OF AMINO ACID SUPPLEMENTATION FOR SOYBEAN MEAL IN PHASE TWO NURSERY DIETS

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ABSTRACT

One experiment involving 100 pigs (20.8 d; 7.0 kg BW) was conducted to determine the extent to which crystalline amino acids can be substituted for soybean meal (SBM) without affecting performance in phase 2 (d 10 to 31 postweaning) nursery pigs. Pigs were blocked based on initial BW and penned in groups of five. All pigs were fed a common phase 1 diet containing 1.50% lysine for the first 10 d following early weaning. After phase 1, pigs (8.3 kg BW) were assigned to one of five dietary treatments (4 pens/treatment) arranged as a 2x2 factorial with a negative control (.80% available lysine). The factorially arranged treatments consisted of two dietary lysine levels (.99 and 1.18% available lysine) with SBM as a source of natural amino acids (NAA) or an amino acid supplemented diet with SBM replaced by an ideal mixture of crystalline amino acids (CAA). Experimental diets were fed for 21 days (phase 2) with gain and efficiency of gain obtained weekly. Blood samples were taken via anterior vena cava puncture on d 0, 7, 14 and 21 of phase 2 and serum was analyzed for blood urea nitrogen (BUN) and creatinine.

From d 0 to 7 and 7 to 14 (phase 2), pigs fed the negative control diet had lower ($P <.05$) gains and gain:feed than those fed NAA or CAA. During d 0 to 7, pigs fed NAA utilized feed more efficiently ($P < .01$) than those fed CAA. From d 7 to 14, pigs fed NAA grew faster ($P < .08$) and were more efficient than those fed CAA ($P < .05$). Pigs fed the negative control diet had lower ($P < .05$) intakes than those fed NAA or CAA. For the entire 21-d experiment, pigs fed the negative control diet had lower gains and gain:feed ($P < .01$) than pigs fed the NAA or CAA diets. Pigs fed NAA had higher ADG ($P < .05$) and gain:feed ($P < .01$) than those fed CAA, and pigs fed 1.18% digestible lysine had higher gain:feed than those fed .99% digestible lysine ($P < .05$). During the overall 21-d experiment, there was an increase in BUN concentrations with increasing lysine level in the NAA diets, but a decrease in BUN when lysine level increased in the CAA diets (interaction, $P < .01$).

These data indicate that adding CAA to the diet of phase 2 nursery pigs improved performance when compared to pigs fed a low protein negative control diet, but did not produce equivalent performance when compared to pigs fed NAA during d 10 to 24 post weaning.

INTRODUCTION

Previous research to determine the lysine requirement for phase 2 nursery pigs fed a phase 2 nursery diet using soybean meal (SBM) as the primary amino acid source resulted in a linear increase in ADG and gain:feed with increasing lysine level in the diet from .95 to 1.40% in .15% increments of total lysine (Rose et al., 1994). This suggests that the lysine (protein) requirement for the rapidly growing 10 kg pig is substantially higher than the current NRC recommendation of .95%. Providing amino acid needs based on suggested ideal amino acid ratio for 10 kg pigs using soybean meal results in protein diets with excesses of many dispensable and indispensable amino acids and is a concern because of the exposure of pigs for the first time to high levels of soybean proteins which have been reported to produce a hypersensitivity response associated with loose stools and decreased performance (Li et al. 1990 and Hankins et al. 1992). Supplementation with crystalline amino acids (CAA) to replace SBM could improve performance by minimizing dietary soybean meal. Therefore, the objectives of this study were 1) to determine the extent to which CAA can be substituted for SBM without affecting performance in phase 2 nursery pigs, 2) to confirm the positive response of nursery pigs fed a phase 2 nursery diet to elevated levels of lysine using SBM as the amino acid source, and 3) to verify that lowering the protein level in these diets will allow for optimal pig performance provided that limiting amino acids are supplemented in the crystalline form.

MATERIALS AND METHODS

A total of 100 pigs averaging 20.8 d of age and 7.0 kg BW were sorted by weight and divided into two weight groups of 50 pigs each. Pigs within each weight group were allotted into ten equal subgroups (five pigs per pen) with stratification based on sex, litter and genotype (Hampshire, Yorkshire and crossbreds). All pigs were fed a common phase 1 diet containing 1.50% total lysine (Table 4.1) for the first 10 d following weaning. On d 10 post weaning, pigs were stratified within each block to obtain similar weights per pen. However, ADG across pen during phase 1 was consistent and reallocation of pigs to equalize mean weights per pen was minimal. Pens within each weight group were then randomly assigned to treatments (4 pens/treatment). Treatments were arranged as a 2 x 2 factorial with a negative control. The negative control diet was formulated to contain .80% digestible lysine (.95% total lysine, Table 4.1). The factorially arranged treatments consisted of two dietary lysine levels (.99 and 1.18% digestible lysine) in 1) the negative control diet with increasing levels of SBM as a supplemental source of lysine and other natural amino acids, NAA (Treatments 2 and 3, respectively), or 2) the SBM based diets with the increased levels of SBM in treatments 2 and 3 replaced with a mixture of CAA (Treatments 4 and 5). The lysine levels were achieved by increasing the amount of SBM or crystalline lysine and other amino acids at the expense of corn starch and sucrose. Diets were formulated on an available amino acid basis using available values listed in Table 4.3 and 4.4. Amino acid levels were supplemented with CAA to meet the ideal ratios according to Baker and Chung (1992). Experimental diets were fed for a 3-wk period starting on d 10 post weaning (phase 2). A sample of each diet was obtained and analyzed for moisture and crude protein (AOAC, 1990). In addition, samples were analyzed for amino acids by the Experiment Station Chemical Laboratories, University of Missouri, Columbia.

The trial was conducted in an environmentally controlled nursery with room temperature maintained initially at 30°C, and decreased by 1°C weekly until temperature reached 26 °C. Pigs were housed in elevated pens (1.14 x 1.5 m) with woven wire flooring and had ad libitum access to feed and water.

Pig BW and feed intake were recorded at initiation, at the end of phase 1, and weekly thereafter to evaluate ADG, ADFI, and gain:feed. Blood samples were obtained via vena cava puncture on d 0, 7, 14 and 21 of phase 2 and serum was analyzed for blood urea nitrogen (BUN) and creatinine concentrations using Roche® reagents (Roche Diagnostic Systems, Sommerville, NJ).

Performance data were analyzed as a randomized complete block design with pen as the experimental unit and blocks based on initial BW. Blood urea nitrogen and creatinine data were analyzed as a split block design with treatment as the main plot and sampling day as a subplot. Analysis of variance was performed using the GLM procedure of SAS (1988). A comparison of the negative control versus the average of diets containing a mixture of NAA and the negative control versus the average of diets containing a mixture of CAA were made. Also the effects of lysine source, lysine level, and the lysine source x lysine level interaction were evaluated by using contrasts.

RESULTS

The calculated and analyzed amino acid composition of phase 2 diets are in Table 4.2. Analyzed values were similar to the calculated values with the exception that the analyzed lysine value for the CAA diet with 1.18% lysine was low. Average daily gain, ADFI and gain:feed during the phase 1 adjustment period following weaning were 134 g/d, 198 g/d and 0.68, respectively.

From d 0 to 7 of phase 2, pigs fed the negative control diet had lower ($P < .01$) ADG and gain:feed than the average of pigs receiving NAA, and lower ADG and gain:feed ($P < .05$ and $P < .01$, respectively) than the average of pigs receiving the CAA diets (Table 4.5). Pigs fed diets containing NAA were more efficient ($P < .01$) than those receiving diets containing CAA. Average daily feed intake was not significantly affected by dietary treatment. During d 7 to 14, ADG, ADFI and gain:feed of pigs fed NAA were greater ($P < .01$, $P < .05$, and $P < .01$, respectively) than for pigs fed the negative control diet. Similarly, pigs fed the CAA diets had greater ADG ($P < .01$), ADFI ($P < .05$), and gain:feed ($P < .05$) than those fed the negative control diet. Daily gains and gain:feed were greater ($P < .08$ and $P < .05$, respectively) in pigs fed NAA than in pigs fed CAA. During d 14 to 21, no differences were observed in ADG, ADFI, or gain:feed among dietary treatments. For the entire 21-d experiment, pigs fed the negative control diet had lower ($P < .01$) ADG and gain:feed than the average of pigs receiving NAA or CAA. Pigs fed SBM had greater ADG and gain:feed ($P < .05$ and $P < .01$, respectively) than pigs fed CAA, and pigs fed 1.18% digestible lysine had greater ($P < .05$) feed efficiency than those fed .99% digestible lysine.

No significant interaction ($P = .18$) between treatment and sampling day was observed for BUN. However, during the overall experimental period (d 7 to 21 of phase 2), pigs fed the control diet had lower ($P < .01$) BUN than the average of pigs fed the NAA diets and higher ($P < .01$) BUN than the average of pigs fed the CAA diets (Table 4.6). There was an increase in BUN concentrations when lysine levels increased in the NAA diets, but a decrease in BUN when lysine increased in the CAA diets (lysine source x lysine level interaction, $P < .01$).

A significant interaction ($P < .05$) between treatment and sampling day (d 7, 14, and 21) was observed for creatinine. At d 7, pigs fed the negative control diet had higher ($P < .01$) creatinine concentrations than those fed NAA or CAA (Table 4.6). At d 14, pigs fed the negative control diet continue to have higher creatinine concentrations than pigs fed NAA ($P < .1$) or CAA ($P < .01$), but the magnitude of the difference was reduced. There was also an increase in creatinine concentrations when lysine level increased in the

NAA diets, but a decrease in creatinine concentrations when lysine levels increase in the CAA diets (lysine source x lysine level interaction, $P < .08$). At d 21, pigs fed the negative control diet had higher ($P < .05$) creatinine concentrations than those fed CAA. An increase in creatinine concentrations was observed when lysine levels were increased in the NAA diets, but a decrease when lysine levels increase in the CAA diets (lysine source x lysine level interaction, $P < .05$).

DISCUSSION

Pigs fed higher lysine diets with either NAA or CAA as an amino acid source had an improved ADG, ADFI and G/F when compared to pigs fed the negative control diet. Average daily feed intake among the dietary treatments was similar. The difference between the negative control diet and the diets with the NAA or CAA is that the lysine level of the negative control diet was lower. The total lysine level of the negative control diet is .95% (.80% available lysine) and the total lysine levels for the NAA and CAA diets are either 1.175% (.99% available lysine) or 1.40% (1.18% available lysine). Thus this experiment agrees with Rose et al. (1994), that the total lysine level of .95% for 10 to 20 kg pigs, recommended by the NRC (1988), is too low.

Gain and G/F were improved for the pigs fed the NAA when compared with pigs fed the CAA. Analyzed lysine level (1.26%) of the CAA diet with the highest level was much lower than the calculated lysine level (1.40%, Table 4.2), which could explain the reduced performance at the high lysine level. Davis reported (1996) that diets based on CAA with high calculated lysine levels (1.62 and 1.65%, respectively) had much lower analyzed lysine levels (1.27 and 1.34%, respectively). An explanation may be that the added crystalline amino acids during the mixing of the diet were not as thoroughly mixed as the natural amino acids. Lysine is also known as an amino acid which is the most heat labile of the indispensable amino acids (Baker, 1994).

The results of this experiment are consistent with results from other experiments where performance of pigs fed NAA diets was superior to that observed for pigs fed the CAA diets. Kerr and Easter (1995) found the same ADG for pigs fed a high protein diet when compared with a low protein diet with added AA, but the lysine level for the high protein diet was lower than the lysine level of the low protein diet with added AA.

Nam and Aherne (1994) found that with increasing the digestible energy (DE) level and lysine:DE ratio, the gain to feed ratio improved. Low protein diets will reduce the efficiency of utilization of energy. The optimum lysine/DE ratio in the experiment from Nam and Aherne (1994) was .95 g of lysine/MJ of DE, but the ideal protein concept was not used. Gatel et al. (1992) used the ideal protein concept and found the maximum growth rate at 1.12 g of lysine/MJ of DE for pigs from 8 to 17 kg.

In this experiment we have not fully explored the energy content of the different diets. Tokach et al. (1995) concluded that adding fat to diets of pigs weaned at 21 days, does not improve performance before 35 days of age. But the diets used were not based on the ideal protein concept. Vaquez et al. (1985) found in a study conducted with humans that during starvation amino acid absorption decreased and that absorption of peptides was improved. Thus the absorption of peptides probably takes less energy and this could mean that absorption of free amino acids requires more energy. Energy content of the diet may be limiting, either because energy utilization is limited by the gut wall cells at the end of the small intestine or the requirements for energy are greater because the pigs fed the diets supplemented with crystalline amino acids need more energy for protein retention, because absorption of free amino acids requires more energy than absorption of peptides.

The BUN values for the pigs fed the NAA diets were much higher than the BUN values for the pigs fed the CAA diets. This agrees with results from Lopez et al. (1994) and Davis (1996). However, BUN values found in this experiment are lower than expected. Low BUN values are consistent with the concept that amino acids are being utilized effectively for protein synthesis and excesses of amino acids in the CAA diets were reduced (Brown and Cline, 1974).

In other experiments suggestions were made that a low amount of other non-essential amino acids could explain the difference in performance between diets based on NAA and CAA. Recommendations are made for levels of proline, between 0.7% and 1.4% (Kirchgessner et al., 1995), glutamic acid, 2% (Roth et al., 1995), and arginine, 0.55% (Fickler et al., 1995). In our experiment, the amino acid levels exceeded all of these recommendations. Davis (1996) observed reduced performance in pigs fed CAA diets when glutamic acid was added to provide 50% of the nitrogen from non-essential amino acids. It appears that the non-essential amino nitrogen may not be the cause of a better feed efficiency of the pigs fed the NAA diets when compared to pigs fed CAA diets.

IMPLICATIONS

These results indicate that gain and efficiency is reduced in phase 2 nursery pigs fed increasing levels of crystalline amino acids when compared to those fed soybean meal.

Nitrogen utilization appears to be improved by using diets based on crystalline amino acids as evidenced by decreased BUN. Further research is needed to determine the cause of superior gain and feed efficiency in pigs fed diets based on natural amino acids when compared to diets with high levels of added crystalline amino acids.

Table 4.1 Composition of experimental diets comparing different protein sources and different lysine levels with the negative control diet.[a]

Ingredients	Phase 1[g]	Phase 2				
		Lysine, %[b]				
		0.80(0.95) Control	0.99(1.175) NAA	1.18(1.40) NAA	0.99(1.175) CAA	1.18(1.40) CAA
Soybean meal, 48% cp	10.00	11.90	19.35	26.78	11.90	11.90
Whey, dried	10.00	5.00	5.00	5.00	5.00	5.00
AP-301[c]	1.50	2.75	2.75	2.75	2.75	2.75
Sucrose	-	7.34	3.67	-	7.02	6.67
Cornstarch	-	7.34	3.67	-	7.02	6.67
Corn, yellow dent	38.06	59.25	59.25	59.25	59.25	59.25
Fishmeal, menhaden	8.00	3.00	3.00	3.00	3.00	3.00
$CUSO_4.5H_2O$	0.07	0.075	0.075	0.075	0.075	0.075
Vitamin TM Premix[g]	0.38	0.38	0.38	0.38	0.38	0.38
Dicalcium Phosphate	1.45	2.08	1.8	1.55	2.08	2.08
Tylan 40-Sulfa[f]	-	0.125	0.125	0.125	0.125	0.125
Sodium Chloride	0.20	0.40	0.40	0.40	0.40	0.40
Calcium Carbonate	-	0.28	0.41	0.53	0.28	0.28
Lysine, HCL	0.26	-	-	-	0.24	0.48
Valine	-	-	-	-	-	0.02
Tyrosine	-	-	-	-	-	0.05
L-Isoleucine	-	-	-	-	0.12	0.25
DL-Methionine	0.09	0.05	0.08	0.10	0.18	0.27
Threonine	-	0.03	0.04	0.06	0.15	0.28
Tryptophan	-	-	0.01	-	0.04	0.07
Lactose, 97%	11.36	-	-	-	-	-
Soybean oil	4.00	-	-	-	-	-
AP-920[d]	3.50	-	-	-	-	-
Flavor, berry	0.10	-	-	-	-	-
Steam rolled oats	10.00	-	-	-	-	-
Neo-Terramycin 10-5[e]	1.00	-	-	-	-	-
Ethoxyquin	0.03	-	-	-	-	-

a As fed basis. Diets were formulated to contain 1.50% lysine, .93% Ca, and .84% P in Phase 1; and .90% Ca, and .75% P in Phase 2, and to exceed the NRC (1988) standards for all nutrients.

b Available lysine levels and total lysine levels (in parentheses). NAA=diets based on natural amino acid sources, CAA=diets based on crystalline amino acid sources.

c Blood meal source, American Protein Corp., Ames, IA.

d Plasma protein source, American Protein Corp., Ames, IA.

e Contained 22 g of neomycin and 11 g of oxytetracline per kg.

f Contained 88 g of tylosin and 88 g of sulfamethazine per kg.

g Vitamins and minerals met or exceed the NRC (1988) requirements. Supplied 9,152 IU of vitamin D_3, 40 IU of vitamin E, 7.3 mg of vitamin K_3, 8.8 mg of riboflavin, 62 mg of niacin, 44 mg of d-pantothenic acid, 587 mg of choline, 1.6 mg of biotin, 3.3 mg of pyridoxine, 1 mg of folic acid, 5.5 mg of thiamine, 40 μg of vitamin B_{12}, .2 mg of Se, 70 mg of Mn, 220 mg of Zn, 220 mg of Fe, 22 mg of Cu, and .44 mg of I, and 540 mg of K per kg of feed during Phase 1, and 6,600 IU of vitamin A, 660 IU of vitamin D_3, 12.8 IU of vitamin E, 5.5 mg of vitamin K_3, 5.1 mg of riboflavin, 36.3 mg of niacin, 33 mg of d-pantothenic acid, 343.9 mg of choline, 20 μg of vitamin B_{12}, .2 mg of Se, 40 mg of Mn, 15 mg of Zn, 150 mg of Fe, and .37 mg of I per kg of feed during Phase 2.

Table 4.2 Calculated (C) and analyzed (A) compositions of crude protein and amino acids comparing dietary protein sources and lysine levels with the negative control diet.[a]

	Lysine, %[b]									
	0.80(0.95)		0.99(1.175)		1.18(1.40)		0.99(1.175)		1.18(1.40)	
Protein source	Control		NAA		NAA		CAA		CAA	
Composition	C	A	C	A	C	A	C	A	C	A
Crude protein	12.99	15.33	15.93	18.46	18.83	21.41	13.60	16.14	14.24	16.29
Lysine	0.95	0.9	1.175	1.16	1.40	1.38	1.175	1.16	1.40	1.26
Tryptophan	0.14	0.17	0.18	0.22	0.21	0.28	0.18	0.23	0.21	0.26
Threonine	0.52	0.61	0.64	0.77	0.77	0.91	0.64	0.75	0.77	0.79
Methionine	0.24	0.31	0.30	0.38	0.35	0.46	0.30	0.4	0.35	0.44
Cysteine	0.24	0.25	0.30	0.31	0.35	0.34	0.30	0.27	0.35	0.26
Valine	0.78	0.81	0.93	0.97	1.07	1.16	0.70	0.86	0.80	0.85
Isoleucine	0.47	0.53	0.61	0.7	0.74	0.83	0.59	0.66	0.71	0.74
Phenylalanine	0.69	0.78	0.84	0.98	0.99	1.14	0.69	0.83	0.69	0.83
Tyrosine	0.51	0.45	0.62	0.58	0.72	0.66	0.51	0.48	0.56	0.51
Leucine	1.43	1.49	1.66	1.79	1.89	2.05	1.43	1.58	1.43	1.58
Arginine	0.77	0.85	1.00	1.15	1.23	1.34	0.77	0.93	0.77	0.9
Histidine	0.5	0.49	0.58	0.6	0.67	0.7	0.50	0.54	0.50	0.52
Glycine		0.67		0.83		0.96		0.72		0.69
Glutamic acid		2.26		3.08		3.54		2.47		2.49
Serine		0.61		0.78		0.88		0.67		0.63
Aspartic acid		1.38		1.83		2.17		1.52		1.49
Taurine		0.07		0.09		0.08		0.08		0.08
Proline		0.9		1.11		1.24		0.95		0.96
Hydroxyproline		0.04		0.04		0.05		0.05		0.04
Ornithine		0.01		0.01		0.01		0.01		0.01
Alanine		0.92		1.08		1.23		0.98		0.96

[a] NAA=diets based on natural amino acid sources, CAA=diets based on crystalline amino acid sources.

[b] Available lysine levels and total lysine levels (in parentheses).

Table 4.3 Percentage apparent ileal digestibility.

	Amino Acids											
Ingredients	LYS	TRP	THR	MET	CYS	VAL	ILE	PHE	TYR	LEU	ARG	HIS
AP-301[a]	95	93	92	97	93	97	79	96	86	97	94	100
Corn, yellow dent	68[b]	67[b]	69[b]	85[b]	77[b]	77[b]	77[b]	80[b]	83[c]	85[b]	82[b]	79[b]
Fishmeal, menhaden	87[b]	78[b]	81[b]	85[b]	71[b]	81[b]	83[b]	81[b]	83[c]	85[b]	87[b]	83[b]
Soybean meal, 48%[b]	84	81	78	84	78	82	83	84	83	84	89	86
Whey, dried	79[b]	81[b]	83[b]	93[b]	92[b]	89[b]	90[b]	83[b]	93[c]	94[b]	86[b]	94[b]

[a] Spray-dried blood meal source; Availability values provided by American Protein Corp., Ames, IA.
[b] Availability values from Heartland Lysine , Inc., 1996. Chicago, IL.
[c] Availability values from L. Lee Southern, 1991.

Table 4.4 Total and available composition of ingredients used in experimental diets. Available compositions were calculated using the apparent ileal digestibility percentages from Table 4.3. Postscripts indicate the source of total composition values.

	AP-301[a]		CORN[b]		WHEY[b]		FISH MEAL[b]		SBM, 48%[b]	
Amino Acids	total	avail	total	avail	total	avail	total	avail	total	avail
LYS	9.00	8.55	0.26	0.18	0.91	0.72	4.84	4.21	3.01	2.53
TRP	1.20	1.12	0.08	0.05	0.16	0.13	0.57	0.44	0.57	0.46
THR	3.60	3.31	0.31	0.21	0.80	0.66	2.71	2.20	1.87	1.46
MET	0.80	0.78	0.18	0.15	0.19	0.18	1.81	1.54	0.67	0.56
CYS	0.60	0.56	0.19	0.15	0.35	0.32	0.61	0.43	0.69	0.54
VAL	9.20	8.92	0.43	0.33	0.68	0.61	3.07	2.49	2.40	1.97
ILE	0.60	0.47	0.31	0.24	0.71	0.64	2.68	2.22	2.20	1.83
PHE	7.10	6.82	0.41	0.33	0.34	0.28	2.45	1.98	2.37	1.99
TYR	2.20	1.89	0.38	0.32	1.14	1.06	1.93	1.60	1.71	1.42
LEU	13.40	13.00	1.06	0.90	1.23	1.16	4.54	3.86	3.65	3.07
ARG	4.00	3.76	0.40	0.33	0.29	0.25	3.86	3.36	3.43	3.05
HIS	7.50	7.50	0.26	0.21	0.20	0.19	1.45	1.20	1.27	1.09

[a] Spray dried blood meal. Total composition values from American Protein Corp., Ames, IA

[b] Total composition values for whey (dried), corn (yellow dent), fishmeal (menhaden) and soybean meal from Heartland Lysine, Inc.(1996), except tyrosine, which was obtained for each ingredient from Lee Southern (1991).

Table 4.5 Effect of protein source and lysine level on performance of phase 2 of the nursery period[a].

Protein source	0.80 (.95) Control	0.99 (1.175) NAA[b]	1.18 (1.40) NAA[b]	0.99 (1.175) CAA[b]	1.18 (1.40) CAA[b]	SEM
	Lysine, %[b]					
d 0 to 7						
ADG, kg[cf]	.26	.38	.42	.34	.36	.031
ADFI, kg	.39	.41	.45	.44	.42	.037
G:F[ceg]	.66	.93	.93	.79	.86	.03
d 7 to 14						
ADG, kg[cei]	.40	.57	.56	.51	.51	.027
ADFI, kg[df]	.68	.83	.76	.79	.76	.035
G:F[cfh]	.59	.69	.73	.65	.68	.02
d 14 to 21						
ADG, kg	.50	.56	.59	.51	.55	.029
ADFI, kg	.85	.94	.92	.85	.84	.029
G:F	.58	.61	.63	.61	.65	.02
d 0 to 21						
ADG, kg[ceh]	.39	.50	.52	.45	.47	.018
ADFI, kg	.64	.72	.71	.69	.67	.028
G:F[cegj]	.61	.74	.77	.68	.68	.01

[a] Data are means of four pens of five pigs each. Pigs averaged 8.3 and 18.1 kg at initiation and termination, respectively.

[b] Available lysine levels and total lysine levels (in parentheses). NAA: natural amino acid source; CAA: crystalline amino acid source

[c] Control vs NAA ($P<.01$).

[d] Control vs NAA ($P<.05$).

[e] Control vs CAA ($P<.01$).

[f] Control vs CAA ($P<.05$).

[g] Lysine source effect ($P<.01$).

[h] Lysine source effect ($P<.05$).

[i] Lysine source effect ($P<.08$).

[j] Lysine level effect ($P<.05$).

Table 4.6 Effect of lysine source and level on blood urea nitrogen (BUN) and creatinine concentrations of phase 2 nursery pigs[a].

	Lys source	Control	NAA[b]		CAA[b]		
Item	Avai. Lys level,%	.80	.99	1.18	.99	1.18	SEM
BUN, mg/dl							
d 0		8.23	7.84	8.67	7.28	7.01	.42
d 7		3.97	5.67	8.52	1.67	1.42	.42
d 14		5.58	6.98	8.94	1.75	1.23	.42
d 21		6.26	7.81	9.46	1.94	1.66	.42
overall (d 7 to 21)[ceg]							
Creatinine, mg/dl							
d 0		1.14	1.08	1.17	1.12	1.12	.02
d 7[ce]		1.08	.95	.94	.98	.95	.02
d 14[dei]		1.02	.93	1.01	.93	.91	.02
d 21[fh]		1.06	1.06	1.12	1.00	.94	.02

[a] Data are means of 4 pens of 5 pigs each. Pigs averaged 8.3 and 18.2 kg at initiation and termination, respectively.

[b] NAA: natural amino acids, CAA: crystalline amino acids; .

[c] Control vs NAA (P<.01).

[d] Control vs NAA (P<.1).

[e] Control vs CAA (P<.01).

[f] Control vs CAA (P<.05).

[g] Lysine source x lysine level interaction (P<.01).

[h] Lysine source x lysine level interaction (P<.05).

[i] Lysine source x lysine level interaction (P<.08).

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