DETERMINATION OF THE LYSINE REQUIREMENT AND POTENTIAL FOR SYNTHETIC AMINO ACID USE IN DIETS OF 5 TO 15 KG PIGS

By

MARI ELLEN DAVIS

Bachelor of Science

North Carolina State University

Raleigh, North Carolina

1994

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 1996

DETERMINATION OF THE LYSINE REQUIREMENT AND

POTENTIAL FOR SYNTHETIC AMINO ACID USE IN

DIETS OF 5 TO 15 KG PIGS

Thesis Approved:

Charles V. Maxwell

Thesis Advisor

Robert Wettemann

William G Luce

Thomas C. Collins

Dean of the Graduate College

ACKNOWLEDGMENTS

I wish to thank Dr. Charles Maxwell, my advisor and mentor, for being a major influence in my scientific endeavors. Also, thanks to Dr. Bob Wettemann and Dr. Bill Luce for serving on my graduate committee and for their assistance and guidance with my studies and research.

I would like to thank Dr. Brenda de Rodas for her expertise in experimental procedures and helping me throughout my graduate work. Also, thanks to Jin Chung and Edwin Broekman for their assistance in data collection during my experiments, and to Kim Brock, Tim Cash, and the many students at the OSU Swine Barn who helped my experiments run smoothly and who were always willing to lend their assistance.

Thanks also to my fellow graduate students for their encouragement and support. Last of all, I wish to thank my parents and many family members for their support both financial and emotional, without whose help this degree would never have been accomplished.

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. Three 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, discussion, implications, and literature cited section.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

Current environmental concern has prompted interest in methods to reduce excess nutrients utilized in modern swine production systems. The use of synthetic amino acids in the formulation of swine diets has received attention as a way to decrease the amount of nitrogen excreted and thereby decrease the potential risk to the environment resulting from swine waste. Excess nitrogen results from the formulation of high protein diets to meet the pig's requirement for lysine. Lysine is considered to be the most limiting amino acid in conventional diets fed to swine, which are usually formulated to meet the animal's lysine requirement. Therefore, balancing the diet for protein is often accomplished by supplying the pig with sufficient protein to meet its lysine requirement, assuming all other amino acids will be present in adequate quantities. This formulation method results in excesses of other amino acids that are not partitioned as lean tissue or needed for normal body turnover. These excess amino acids are instead catabolized and excreted as urinary nitrogen in the form of urea.

One method to decrease the amount of protein in the diet and as a result decrease the quantity of nitrogen excreted in swine waste is to formulate rations with synthetic lysine as a substitute for a portion of the protein ingredient in the diet. This would allow the pig's lysine requirement to be met while lowering the protein content of the diet and consequently, lowering the amount of excess amino acids catabolized and excreted as nitrogen waste. As diets are formulated to meet the pig's ideal balance of amino acids, dietary protein is better utilized for lean tissue production resulting in a nutrient-efficient swine production system with less protein excreted as urinary nitrogen. Additionally, the potential possibly exists to partially replace a portion of the expensive protein ingredients often utilized in the diets of young pigs.

Synthetic forms of methionine, threonine, and tryptophan are also available at feed grade prices and can be utilized to formulate swine diets to better meet the pig's protein requirement.

With the use of synthetic amino acids to decrease the level of dietary protein, isoleucine becomes the most limiting amino acid not available at an economically feasible price. Therefore, the pig's requirement for isoleucine must be met by the natural protein portion of the diet. Formulating swine diets with synthetic lysine, methionine, threonine, and tryptophan results in the need to balance the protein portion of the diet to meet the pig's requirement for isoleucine, the next limiting amino acid.

A series of three experiments were conducted to determine the potential for the use of synthetic amino acids as a substitution for a portion of the protein content in nursery pig diets. The specific objectives were: 1) to determine the lysine requirement of conventionally weaned pigs using natural protein sources during the first two weeks postweaning, 2) to determine if equivalent performance can be obtained when synthetic lysine is used to reach the same dietary lysine level while lowering the diet's protein content, and 3) to attempt to explain why pigs perform poorly when synthetic amino acids are substituted for a natural protein source in the diet.

CHAPTER II

REVIEW OF LITERATURE

Many studies have been performed to determine the lysine and isoleucine requirements of the 5 to 15 kg weanling pig, though their attempt to conclusively define these needs has been unsuccessful. This variability in results is most likely due to the various conditions under which the experiments were conducted. Variations in factors which impact lean tissue gain such as feed composition and ingredients, availability of nutrients, genetics, and disease status can all affect the outcome of trials attempting to define the weanling pig's amino acid requirement. With the development of improved dietary formulation which has dramatically improved performance and the advent of the practice of segregated early weaning, interest in the amino acid requirements of young pigs has surfaced.

This review will summarize studies conducted in an attempt to define the lysine requirements of the 5 to 15 kg pig. In addition, the concept of ideal protein and low protein diets supplemented with synthetic amino acids will be discussed, as well as various factors that may influence the pig's response to increasing dietary lysine and(or) addition of synthetic amino acids such as dietary whey content and non-essential nitrogen requirements.

Lysine

Lysine is considered to be the most limiting amino acid in conventional nursery pig diets usually consisting of complex, highly digestible protein sources. As a result, much of the work on amino acid requirements has been conducted to better determine the pig's need for lysine to maximize performance in various production stages. The National Research Council (1988) lists the lysine requirement for 5 to 15 kg pigs as 1.15% of the diet, but it is common practice in the industry to feed levels far in excess of this recommendation.

Work at Kansas State University with early weaned pigs suggests the lysine requirement for weanling pigs may be much higher than the level recommended by NRC (1988). Owen et al. (1994) conducted an experiment in which 14 to 18 day old pigs were fed one of six diets (consisting of corn, dried whey, plasma protein, fish meal, blood meal, soybean meal, and supplemental synthetic amino acids) varying in lysine from 1.20% to 1.95% of the diet. During the time from d 0 to 7 and d 0 to 14, ADG and FE increased with increasing dietary lysine level. From d 0 to 7, ADG appeared to reach a maximum between 1.65% and 1.80% lysine while FE was improved at lysine levels up to 1.80% dietary lysine. From d 0 to 14, both ADG and FE were maximized at 1.65% lysine in the diet. They concluded that pigs weighing less than 11 pounds required 1.70% lysine in the diet and that 11 to 15 lb pigs required 1.50% to 1.60% dietary lysine.

Lepine et al. (1991) evaluated the response of pigs averaging 6.1 kg and weaned at 23 ± 2 days of age to determine their response to added levels of L-lysine hydrochloride to corn-soybean meal diets with and without additional dried whey supplementation. Feed intake decreased with addition of L-lysine hydrochloride in diets with and without supplemental whey. Growth rate increased with increasing lysine level from 1.10% to 1.50% in diets containing dried whey, but little improvement was observed above the 1.10% level in diets without added whey. This suggests lysine may not be the most limiting factor in corn-soybean meal diets fed to weanling pigs, but instead a highly digestible carbohydrate source is necessary before benefits from additional lysine can be realized.

There is additional evidence suggesting the lysine requirements of young pigs may be higher than the NRC (1988) recommendation. Mitchell, Jr. et al. (1965) evaluated the lysine needs of the 5 kg pig at two weeks of age. They found the lysine requirement of pigs at this stage of production to be 1.24% to 1.34% of the diet on the basis of weight gain. Two trials were conducted by Pollmann et al. (1983) to determine the effect of varying lysine level in starter diets. They determined that 3 to 4 week old weaned pigs fed corn-soybean meal diets containing 20% dried whey required 1.25% dietary lysine.

Lewis et al. (1981) conducted an experiment to evaluate the lysine requirement of 5 kg pigs fed corn-soybean meal diets and to determine how the requirement was affected by added dietary fat. Pigs were fed two levels of fat (0% and 5%) and six levels of lysine (.95% increasing by .10% to 1.45%) arranged in a 2 x 6 factorial design. Weight gain and feed efficiency improved as the lysine level increased from .95% to 1.25% of the diets, but decreased at the 1.35% level and above. Feed intake showed a tendency to increase as the lysine level of the diet increased. Results indicated no lysine x fat interaction, suggesting the addition of fat did not alter the lysine requirement.

A similar study by Cera and Mahan (1987) evaluated the lysine requirement of 6 kg pigs by feeding four levels of lysine with and without 6% supplemental corn oil. Pigs fed corn-soybean meal-dried whey diets required 1.15% dietary lysine, while pigs fed the same diet with added corn oil required 1.22%. These data suggest feeding additional energy increased the lysine requirement when it was expressed on a percentage basis.

Research concludes the lysine requirement can be affected by the type of feedstuff used in the diet and its amino acid digestibility. Martinez and Knabe (1990) conducted an experiment to determine the digestible lysine requirement of pigs weaned at 28 days of age and with an average weight of 6.1 kg. Pigs were fed corn-soybean meal-peanut meal diets with lysine hydrochloride added in equal increments from .80 to 1.30% and a control diet at 1.14% lysine without peanut meal. Addition of lysine hydrochloride increased the digestibility of lysine and tended to reduce the digestibility of some other amino acids. Average daily gain, daily feed intake, and gain:feed increased with increasing lysine level up to 1.20%, but performance was similar to the control diet which contained 1.15% lysine and was devoid of peanut meal. From these results, they concluded the digestible lysine requirement for starter pigs to be 1.03% compared to a 1.15% requirement for total lysine.

Campbell and Taverner (1988) conducted an experiment to assess the 8 to 20 kg pig's response to varying protein levels to determine the requirement for protein and amino acids. Dietary concentrations of protein and lysine to support maximum growth were 187 g protein/day, or 13.1 g lysine/day. A similar study conducted by Leibholz and Parks (1987) investigated the lysine requirement of pigs from 7 to 56 days of age. They observed that 7 to 28 day old pigs required at least 12.7g lysine/kg DM, while pigs from 28 to 56 days of age needed no more than 12.0 g lysine/kg DM.

Thaler et al. (1986) conducted an experiment to determine the lysine requirement of 3-week old pigs and to determine if benefits from additional lysine during this stage of production would affect subsequent growth performance and carcass characteristics. Optimum pig performance when pigs were fed from weaning to 20 kg was observed at 1.10% dietary lysine, but this increased performance was not sustained to market weight.

Increasing the protein level of the diet may result in an increase in the pig's lysine requirement. Lin and Jenson (1985) evaluated the lysine requirement of weaned pigs in diets ranging from 17.5 to 21.5% CP. They found the lysine requirement increased by .04% for each 1% increase in CP, so the diet with 19.5% CP and 1.19% lysine resulted in optimum performance when fed to weaned pigs. Similar results were obtained when Campbell (1978) compared the performance of early weaned pigs fed 14.6% and 16.6% CP with supplemental lysine to pigs fed a control diet of 20% CP and 1.10% lysine. Pigs fed 16.6% CP had superior performance over those fed 14.6% CP at the same lysine level and 1.26% lysine was needed for the 16.6% CP diets to yield the same performance as pigs fed the 20% CP control diet at 1.10% lysine. In contrast to these findings, Aherne and Nielson (1983) discovered that pigs fed 20% CP had better performance than those fed 18% CP. However, this response was independent of lysine level since pigs fed 1.15% lysine had similar performance when fed either 18% or 20% CP.

Research suggests there is a minimum requirement for protein in the diet. Pollmann et al. (1984) found weanling pigs fed corn-soybean meal diets with 18.5 to 22.5% CP had better performance than those receiving 17% CP diets supplemented with lysine hydrochloride. Many studies report no difference in performance in pigs fed a low protein diet supplemented with lysine and a higher protein diet formulated to the same lysine level. Meade et al. (1965)

observed that supplementation of a 16% CP corn-soybean meal diet with lysine and methionine resulted in performance equivalent to an 18% CP diet. Katz et al. (1973) conducted a similar study on 5 week old pigs and found a 16% CP diet supplemented with lysine gave results equal to those pigs fed an unsupplemented 19% CP diet. Lunchick et al. (1978) conducted an experiment to determine the optimum protein and lysine level for 9 to 20 kg pigs. They found pigs fed 16 and 18% CP diets supplemented with lysine had performance equal to pigs fed 20% CP diets. From these results, they suggest the protein and lysine levels required for these pigs are 16% CP and .92% lysine and explain that the lower lysine levels required at low protein diets may be due to the improved availability of synthetic lysine used to supplement the diets when compared to lysine availability of natural protein sources.

In conclusion, the lysine requirement may be dependent upon pig performance. It can be influenced by such factors as environmental conditions, disease status, the availability of the lysine in the diet of the pig, and the pig's potential for lean gain and rate of growth. The variability observed in studies to determine the lysine requirement of pigs is presumably due to the various conditions under which the experiments were conducted. An increase in lean tissue gain may augment the lysine requirement, suggesting the pig's need for lysine may be contingent on performance.

Whey

Some of the improvements observed in pig performance when lysine is increased in the diet have been attributed to the whey component present in most starter pig diets. Pals and Ewan (1978) reported that weanling pigs were more capable of utilizing the energy and protein in whey than in grain-soybean sources. Therefore, many studies have been conducted to determine the feeding value of whey compared to other common ingredients included in young pig diets.

Cieslak et al. (1986) conducted a series of experiments to assess the value of liquid whey relative to corn-soybean meal diets. In the first two trials, growing pigs between 14 and 16 kg were fed corn-soybean diets with one of three dietary protein levels (high, medium, or low) and administered either water or liquid cheddar cheese whey. Though protein intake was lower for pigs consuming the low protein-whey diet as compared to the high protein-water diet, growth rate was not compromised. Pigs fed liquid whey had improved total protein efficiency (kg gain/kg protein intake) over those fed the control diet. In a third trial, pigs were fed one of six crude protein levels (3, 5, 8, 10, 12, and 14% CP) with the dietary protein supplied by 50% corn and 50% from either soybean protein or dried whey. Growth rate was higher for each unit of crude protein when 50% of the dietary protein was supplied by whey. They concluded that dried whey is a better protein supplement to corn diets than soy protein.

An additional study by Cinq-Mars et al. (1986) evaluated the feeding value of whey protein concentrate in corn-soybean meal diets fed to pigs weaned at 3 to 4 weeks of age. Pigs were fed one of three dietary treatments: a control diet consisting of corn, soybean meal, and fish meal; a second diet with liquid whey protein concentrate added to completely replace fish meal; and a third diet with liquid whey protein concentrate replacing fish meal and 74% of the total soybean meal. Lysine was maintained at 1.20% in all three diets. Average daily gain was 33% higher and feed efficiency was improved in pigs fed either level of whey protein concentrate compared to the control. Results suggested liquid whey protein concentrate could be used to replace fish meal and soybean meal as a protein and energy source to improve pig performance.

Tokach et al. (1989) evaluated the protein (lactalbumin) and carbohydrate (lactose) components of dried whey to determine which is responsible for improved pig performance. Pigs with an average initial weight of 4.8 ± 2.2 kg were fed one of six corn-soybean meal-based dietary treatments: 1) no whey (control); 2) 20% whey; 3) 14.4% lactose; 4) 2.1% lactalbumin; 5) 14.4% lactose and 2.1% lactalbumin; and 6) 8.34% whey protein concentrate. Pigs fed whey had increased average daily gain and improved feed efficiency compared to pigs fed the control diet. Performance among pigs fed the whey or whey-component diets was similar, but all resulted in improved performance over the control diet. In addition, there was no additive effect when the lactose and lactalbumin components were fed together.

A similar study conducted by Mahan (1992) to evaluate dried whey, lactalbumin, and lactose fed to weanling pigs determined that the addition of lactalbumin and cornstarch to a corn - soybean meal diet did not improve pig performance, while addition of lactose and an amino-acid mixture did. The results of this experiment suggested that benefits from the addition of dried whey to weanling pig diets seemed to be from the carbohydrate component. Additionally, an available carbohydrate source instead of protein may have been the most limiting factor in weanling pig diets and needed to be present before improvements from additional protein were realized.

Ideal Protein

An ideal protein can be defined as one which contains an amino acid pattern conforming exactly to the animal's requirement. In such a case, all indispensable amino acids and the sum of the protein's dispensable amino acids would be equally limiting (Bercovici and Fuller, 1995). The ARC (1981) published recommendations for an ideal protein for swine defined as individual essential amino acid ratios relative to lysine (Table 2.1). Efforts have since been conducted to better define this pattern of ratios to more closely meet the needs of the young pig.

Fuller and Wang (1990) suggested the amino acid pattern estimated by the ARC (1981) to be ideal may not be a good representation of the pig's requirements since it was derived from a conglomeration of data from several sources. Two series of experiments were conducted to reassess the ARC (1981) recommendation. In the first study, an estimation was made to optimize the amino acid pattern in the diet so that each individual amino acid and the sum of the dispensable amino acids would be equally limiting. This served as the experimenters' definition of ideal protein. The resulting amino acid pattern (Table 2.1) showed the optimum level of indispensable amino acids in dietary protein according to Fuller and Wang (1990). The second series of experiments focused on amino acid requirements for deposition of tissue protein. Tissue protein accretion requirements were found to be similar to the amino acid composition in body tissue, although threonine and the sulfur amino acids had slightly higher requirements than levels present in tissue.

Several experiments were conducted by Chung and Baker (1991) with weanling crossbred pigs to develop a chemically defined amino acid diet that would allow pigs to grow at least as efficiently as those fed typical corn-soybean meal-whey diets. In the first experiment, a comparison was made between pigs fed the chemically defined amino acid diet and those fed a corn-soybean meal-whey diet. Next, an attempt was made to establish an optimum dietary indispensable amino acid profile and corresponding levels of dispensable amino acids. After this optimum amino acid profile was determined, the third experiment compared this final purified amino acid diet with the corn-soybean meal-whey positive control. Finally, nitrogen retention in pigs fed the final purified diet was compared to that of pigs fed the same positive control diet.

The first experiment determined that weight gain and feed efficiency of pigs fed the corn-soybean meal-whey diet was superior to those fed the amino acid diet containing 13.56% protein. In the second experiment, four diets containing amino acid mixtures with indispensable amino acids fed at various levels were fed to establish an amino acid profile that provided the same performance as the corn-soybean meal-whey positive control diet. This amino acid mixture was then compared again to the positive control diet in Experiment 3 and resulted in similar weight gain and feed efficiency. Experiment 4 determined nitrogen retention of the amino acid diet was superior to the intact protein fed in the positive control diet, and this profile was established as ideal for pig growth.

Chung and Baker (1992) in a later experiment attempted to improve on this ideal amino acid profile and compare their pattern with the one established by Wang and Fuller (1989) and the amino acid requirement pattern recommended by the NRC (1988). Unlike the pattern derived by Wang and Fuller (1989), the ideal protein pattern of Chung and Baker (1991) included arginine and histidine. Weight gain and feed intake were similar when pigs were fed the improved amino acid pattern and the Wang and Fuller pattern, while pigs fed the original amino acid pattern from the previous experiment and the pattern recommended by NRC (Table 2.1) gained more slowly. Gain per unit of nitrogen intake was better for pigs fed the improved amino acid pattern. From these results the improved amino acid profile (Illinois Ideal Amino Acid Pattern, Table 2.1) was found to be superior to that proposed by Wang and Fuller and NRC.

Yen et al. (1986) conducted an experiment to examine the response of 50 to 90 kg pigs to increasing lysine while maintaining the same ratios to other indispensable amino acids. Though crude protein levels were lower and lysine levels were higher than those recommended by the ARC, growth of the pigs was improved. Lowering the level of crude protein in the diet with the use of synthetic amino acids was possible because the diet was able to be formulated to more closely meet the protein needs of the pigs, since it supplied a well balanced protein to better provide the ideal pattern required by the pig.

Nitrogen must also be considered when balancing rations on an ideal protein basis since it is necessary for the synthesis of dispensable amino acids. Wang and Fuller (1989) suggested an ideal profile of dietary amino acids was such that a given protein intake resulted in highest nitrogen retention. They conducted an experiment in which a quantity of each amino acid was removed without affecting nitrogen retention and calculated a pattern in which all indispensable amino acids were equally limiting. Ratios of essential:non-essential amino acids were fed and maximum nitrogen retention was found to be between 50:50 and 57:43 when lysine was fed at 7 to 8 g/16 g nitrogen. A broken line model was fitted and the optimum ratio of essential:non-essential was determined to be 45:55.

The concept of ideal protein as applied to the growing pig is a definition of the animal's amino acid requirements in terms of relative amounts of each individual amino acid, rather than in quantitative absolute requirements. For example, the essential amino acids required for 1 gram of lean deposition may be the same in all cases, but an individual pig's requirement may vary depending on its potential for lean gain (Cole, 1985). Also, meeting the pig's protein requirement using a range of ingredients makes balancing diets on an ideal protein basis difficult since amino acids may be under- or over-supplied. In order for a diet to be formulated on the basis of ideal protein, the crude protein of the diet must be lowered and deficiencies of amino acids overcome with supplementation of synthetic amino acids.

Synthetic Amino Acids

Synthetic amino acids are added to swine diets in an attempt to optimize animal production by improving the pig's utilization of dietary protein through the achievement of a better amino acid balance. This allows the amino acid composition of the diet to be more clearly defined, resulting in the ability to formulate diets that better meet the pig's amino acid requirement. Also, crude protein in the diet can be reduced which decreases nitrogen excretion and results in more environment-friendly swine production (Wallace and Chesson, 1995). It is currently common for diets to be formulated with crude protein reduced by 2% and supplemented with synthetic lysine, but further reductions in crude protein often result in unsatisfactory gain and carcass quality. Therefore, the benefits from synthetic amino acid use cannot yet be realized since, in many cases, similar gain and efficiency are not obtained when synthetic amino acids are substituted for a portion of the protein content in the diet

Some suggest pig performance suffers when high levels of synthetic amino acids and low crude protein levels are fed because amino acid imbalances occur as amino acids other than lysine become limiting. In a study comparing opaque-2 corn with normal corn, Stables and Carr (1979) found that feed refusals were more common when lysine and methionine were added either singly or in combination to a normal corn diet. Intake returned to normal when the diet was supplemented with tryptophan. This suggests that tryptophan may have been more limiting in the normal corn diet and addition of lysine and methionine without tryptophan caused an amino acid imbalance that resulted in depressed feed intake. This imbalance was eliminated with the addition of tryptophan to the diet, and did not occur in the opaque-2 corn diet because of the higher tryptophan present in the hybrid variety.

Russell et al. (1983) conducted an experiment to determine the limiting amino acids in a lysine-fortified 12% protein corn-soybean meal diet for pigs weighing 20 to 35 kg. This 12% basal diet was supplemented with four levels of tryptophan and compared to a 16% protein positive control diet. Tryptophan supplementation at any level failed to improve average daily gain and feed efficiency, and pigs fed the 16% protein positive control diet performed better than pigs fed the 12% protein, lysine-supplemented diet. When threonine was added in addition to tryptophan, nitrogen retention and plasma urea nitrogen were decreased and gain and efficiency were similar to pigs fed the 16% protein positive control diet. The greatest improvement was observed when both threonine and tryptophan were added to the 12% protein diet indicating that threonine may be the third limiting amino acid while tryptophan is only slightly less limiting in low protein diets.

Corley and Easter (1980) found that growing pigs do not respond to supplementation of synthetic amino acids when the protein level of the diet is too low. Pigs fed a 10% crude protein diet supplemented with .48% lysine and .02% tryptophan had inferior growth rate and feed efficiency when compared to a 16% protein corn-soybean meal control diet. Yet, when fed a 12% crude protein diet supplemented with .25% lysine and .02% tryptophan, growth and efficiency were similar to pigs fed the 16% protein control diet.

A similar study was performed by Kephart and Sherritt (1990) in which growing pigs were fed corn-soybean meal diets. The control diet formulated at 115% of the 20 kg pig's lysine requirement was altered by varying the ratio of corn:soybean meal to achieve a 10% crude protein content. This low protein diet was then supplemented with synthetic amino acids to make values of lysine, tryptophan, threonine, isoleucine, methionine, and valine equivalent to the control diet. Pigs fed the 10% crude protein, amino acid supplemented diet did not gain as well or as efficiently as pigs fed the corn-soybean meal control diet. The authors suggest this may be due to the different rates of absorption of free amino acids from those present in intact proteins.

Brudevold and Southern (1994) evaluated the use of supplemental amino acids to obtain optimum growth and feed efficiency in low protein sorghum-soybean meal diets for the 10 to 20 kg pig. In the first two experiments the pigs were allowed ad libitum access to feed. Pigs fed the low protein, amino acid-supplemented diet had similar performance as pigs fed a 21.81% crude protein diet with no additional amino acids. In the next two experiments, pigs were fed twice daily so that their daily intake was an amount estimated to be equivalent to ad libitum intake. Pigs fed the low protein, amino acid-supplemented diets in these trials performed poorer than pigs fed the 21.81% crude protein positive control diet. The authors conclude that the low protein diets may not have been formulated to meet the pigs' complete amino acid requirements since limit feeding a deficient diet will result in poorer performance than feeding that diet on an ad libitum basis.

Russell et al. (1987) conducted a study to determine the limiting amino acids in an 11% crude protein corn-soybean meal diet for growing pigs. Neither the addition of methionine nor glutamic acid to the 11% crude protein basal diet resulted in improved gain or feed efficiency. From this it was concluded that methionine and nitrogen were not limiting in an 11% crude protein diet for 20 to 40 kg pigs. Addition of isoleucine and valine resulted in improved daily gain and feed efficiency, but left the uncertainty of which was responsible for the improvement. A follow-up study determined that the addition of isoleucine alone resulted in no improvement and actually decreased daily gain. The addition of valine improved daily gain and was not different from a 16% crude protein positive control diet, suggesting valine is the fourth limiting amino acid in low protein, corn-soybean meal diets for growing pigs.

Spiekers et al. (1991) suggest the reason that many previous experiments attempting to feed low protein amino acid supplemented diets failed was because they did not supplement the diet with isoleucine. In this experiment, 10 to 25 kg pigs were fed one of four diets: a high soybean meal diet; a high soybean meal diet with synthetic amino acid supplementation; a low soybean meal diet; or a low soybean meal diet with synthetic amino acid supplementation. Supplementation with synthetic amino acids included lysine, methionine, threonine, tryptophan, and isoleucine. There was no difference in performance between the high and low soybean meal diets or between the diets with or without supplemental amino acids. The authors contribute their success with synthetic amino acid supplementation to the addition of isoleucine, and consider it to be the fifth limiting amino acid when feeding low protein diets.

Roth et al. (1993) conducted a study with 50 kg female pigs to determine how low dietary protein can be reduced and still support maximum nitrogen retention with minimal nitrogen excretion. Dietary crude protein was reduced in 7 steps and the proportion of each essential amino acid was held constant to lysine by additions of amino acids. Maximum nitrogen retention and minimum excretion resulted when daily protein intake was decreased to 2 g N/kg $LW^{0.75}$. Lower reduction of the protein supply resulted in decreased nitrogen excretion indicating a deficiency of amino nitrogen. Therefore, a minimum crude protein requirement was derived based on regression analysis as 12.6 g/kg $LW^{0.75}$ and an essential:non-essential amino acid ratio of 47:53 was recommended.

Nitrogen and Dispensable Amino Acids

Several studies suggest that problems with lowering the protein content of a diet and substituting synthetic amino acids is due to a deficiency in nitrogen needed to synthesize dispensable amino acids. The attempt to make the diet balanced by providing indispensable amino acids in ideal ratios reduces the amount of excess amino acids available to be broken down to amino nitrogen and used for dispensable amino acid synthesis.

Fickler et al. (1994) fed a chemically defined amino acid diet to 10 to 15 kg pigs and compared growth and nitrogen retention in pigs fed diets containing grain, soybean meal, fish meal, and skim milk powder. The amino acid diet contained ideal ratios of essential amino acids according to Chung and Baker (1991) and a mixture of non-essential amino acids including alanine, aspartic acid, glutamic acid, glycine, proline, and serine. Pigs consuming the amino acid diet experienced a 24% decrease in growth rate compared to pigs fed control diet. The amino acid diet resulted in a 14% lower nitrogen retention and a 15% increase in percentage of nitrogen utilized. The authors concluded that the amount of dispensable amino acids should be raised, and the pattern of indispensable amino acids improved, in order to obtain satisfactory growth and nitrogen retention.

Mitchell, Jr. et al. (1968) conducted a study to determine the effect on performance of glutamic acid addition to a semi-synthetic amino acid diet for 10 kg pigs. This study was conducted after an apparent amino acid imbalance was observed in a previous experiment due to addition of glutamic acid to make the test diets isonitrogenous. Glutamic acid was added to a 10.84% casein diet at 0.00, 1.10, 2.59, and 7.20%. This produced an essential:non-essential amino nitrogen ratios of 1.40, 1.20, 1.00, and 0.66, respectively. Nitrogen retention was greatest when glutamic acid was added at 2.59%, or to provide a 1:1 ratio of essential:non-essential amino nitrogen. These results indicate that essential and non-essential amino acids should provide 50% of the total dietary nitrogen.

Roth et al. (1994) suggested that some of the amino acids believed to be dispensable may actually be required in the diet, particularly when dietary protein content was reduced. Alanine, arginine, aspartic acid, glutamic acid, glycine, proline ,and serine were each omitted from a chemically defined amino acid diet fed to 14 kg pigs. As each amino acid was omitted, it was replaced by the remaining amino acids in the same proportions so that it was equivalent in nitrogen to the control diet containing a complete mixture of these amino acids. Nitrogen accretion and utilization were not affected by the omission of alanine, aspartic acid, glycine, or serine from the control diet. When arginine, glutamic acid, or proline were omitted from the diet, nitrogen accretion decreased by 50%, 6%, and 8%, respectively. These data indicate that alanine, aspartic acid, glycine, and serine are completely dispensable in the growing pig, while arginine, glutamic acid and proline must be provided in the diet.

Table 2.1. Comparison of four ideal protein amino acid patterns relative to lysine.

	Amino acid pattern (% of lysine)[a]			
Amino acid	ARC (1981)	NRC (1988)	WFIP (1990)	IIP (1992)
Arginine	N/A	42	N/A	42
Histidine	33	26	N/A	32
Isoleucine	55	56	60	60
Leucine	100	74	110	100
Lysine	100	100	100	100
Methionine + Cystine	50	52	63	60
Phenylalanine + Tyrosine	96	81	120	95
Threonine	60	59	72	65
Tryptophan	15	15	18	18
Valine	70	59	75	68

[a] Amino acid patterns were: ARC=Agricultural Research Council Requirement Pattern; NRC=National Research Council Requirement Pattern; WFIP=Wang and Fuller Ideal Amino Acid Pattern; IIP=Illinios Ideal Amino Acid Pattern.

LITERATURE CITED

Aherne, F.X., and H.E. Nielson. 1983. Lysine requirement of pigs weighing 7 to 19 kg liveweight. Can. J. Anim. Sci. 63:221.

ARC. 1981. The nutrient requirements of pigs. Commonwealth Agricultural Bureaux, Slough, U.K.

Bercovici, D. and M.F. Fuller. 1995a. Amino acids for nonruminants. In: R.J. Wallace and A Chesson (Ed.). Biotechnology in Animal Feeds and Animal Feeding. p. 101. VCH; Weinheim, Germany.

Bercovici, D. and M.F. Fuller. 1995b. Individual amino acids in nonruminant animal nutrition. In: R.J. Wallace and A. Chesson (Ed). Biotechnology in Animal Feeds and Animal Feeding. p. 105. VCH; Weinheim, Germany.

Brudevold, A.B. and L.L. Southern. 1994. Low-protein, crystalline amino acid-supplemented, sorghum-soybean meal diets for the 10- to 20-kilogram pig. J. Anim. Sci. 72:638.

Campbell, R.G., 1978. The response of early weaned pigs to sub-optimal protein diets supplemented with synthetic lysine. Anim. Prod. 26:11.

Campbell, R.G. and M.R. Taverner. 1988. The tissue and dietary protein and amino acid requirements of pigs from 8.0 to 20.0 kg live weight. Anim. Prod. 46:283.

Cera, K.R. and D.C. Mahan. 1987. Lysine requirement with or without supplemental corn oil for weanling swine. J. Anim. Sci. 65:124(Suppl. 1).

Chung, T.K. and D.H. Baker. 1991. A chemically defined diet for maximal growth of pigs. J. Nutr. 121:979.

Chung, T.K. and D.H. Baker. 1992. Ideal amino acid pattern for 10-kilogram pigs. J. Anim. Sci. 70:3102.

Cieslak, D.G., N.J. Benevenga, and R.H. Grummer. 1986. The evaluation of fresh sweet liquid whey as a protein supplementation to maize for growing pigs. Animal Feed Science and Technology. 14:171.

Cinq-Mars, D., G. Belanger, B. Lachance, and G.J. Brisson. 1986. Performance of early-weaned piglets fed diets containing various amounts of whey protein concentrate. J. Anim. Sci. 63:145.

Cole, D.J.A. 1985. Amino acid nutrition of the pig. In: D.J.A. Cole and W. Haresign (Ed). Recent Developments in Pig Nutrition. p. 71. Butterworths, London.

Corley, J.R. and R.A. Easter. 1980. Amino acid supplementation of low-protein diets for growing and finishing pigs. J. Anim. Sci. 51:191(Suppl. 1).

Fickler, J., F.X. Roth and M. Kirchgessner. 1994. Use of a chemically defined amino acid diet in a N-balance experiment with piglets 1. Communication on the importance of non-essential amino acids for protein retention. J. Anim. Physiol. and Anim. Nutr. 72:207.

Fuller M.F. and T.C. Wang. 1990. Digestible ideal protein – a measure of dietary protein value. Pig News and Info. 11:333.

Katz, R.S., D.H. Baker, C.E. Sasse, A.H. Jensen and B.G. Harmon. 1973. Efficacy of supplemental lysine, methionine, and rolled oats for weanling pigs fed a low-protein corn-soybean meal diet. J. Anim. Sci. 37:1165.

Kephart, K.B. and G.W. Sherritt. 1990. Performance and nutrient balance in growing swine fed low-protein diets supplemented with amino acids and potassium. J. Anim. Sci. 68:1999.

Leibholz, J. and J.R. Parks. 1987. Lysine supplementation of diets for pigs between 7 and 56 days of age. Anim. Prod. 44:421.

Lepine, A.J., D.C. Mahan and Y.K. Chung. 1991. Growth performance of weanling pigs fed corn-soybean meal diets with or without whey at various L-lysine-HCl levels. J. Anim. Sci. 69:2026.

Lewis, A.J., E.R. Peo, Jr., B.D. Moser and T.D. Crenshaw. 1981. Lysine requirement of pigs weighing 5 to 15 kg fed practical diets with and without added fat. J. Anim Sci 51:361.

Lin, C.C. and A.H. Jenson. 1985. The lysine requirement of weanling pigs at different levels of dietary protein. J. Anim. Sci. 61:98(Suppl. 1).

Lunchick, C., A.J. Clawson, W.D. Armstrong and A.C. Linnerud. 1978. Protein level, lysine level and source interaction in young pigs. J. Anim. Sci. 47:176.

Mahan, D.C. 1992. Efficacy of dried whey and its lactalbumin and lactose components at two dietary lysine levels on postweaning pig performance and nitrogen balance. J. Anim. Sci. 70:2182.

Martinez, G.M. and D.A. Knabe. 1990. Digestible lysine requirement of starter and grower pigs. J. Anim. Sci. 68:2748.

Meade, R.J., J.T. Typpo, M.E. Tumbleson, J.H. Goihl, and H. von der Mehden. 1965. Effects of protein source and level, and lysine and methionine supplementation on rate and efficiency of gain of pigs weaned at an early age. J. Anim. Sci. 24:626.

Mitchell, Jr., J.R., D.E. Becker, A.H. Jensen, H.W. Norton, and B.G. Harmon. 1965. Lysine need of swine at two stages of development. J. Anim. Sci. 24:409.

Mitchell, Jr., J.R., D.E. Becker, B.G. Harmon, H.W. Norton and A.H. Jenson. 1968. Some amino acid needs of the young pig fed a semi-synthetic diet. J. Anim. Sci. 27:1322.

NRC. 1988. Nutrient Requirements of Swine (9th Ed..) National Academy Press, Washington, DC.

Owen, K.Q., J.L. Nelssen, R.D. Goodband, M.D. Tokach, B.T. Richert, K.G. Friesen, J.W. Smith, II, J.R. Bergstrom, and S.S. Dritz. 1994. Dietary lysine requirements of segregated early-weaned pigs. Kansas State University Swine Day. pp. 37-41.

Pals, D.A. and R.C. Ewan. 1978. Utilization of the energy of dried whey and wheat middlings by young swine. J. Anim. Sci. 46:402.

Pollmann, D.S., G.L. Allee, and S. Pope. 1983. Effects of weaning age, source of whey, and lysine level on starter pigs. J. Anim. Sci. 57:86(Suppl. 1).

Pollmann, D.S., G.L. Allee, M.E. Johnston, and R.H. Hines. 1984. Protein and lysine levels in starter pig diets. J. Anim. Sci. 59:248(Suppl. 1).

Roth, Von F.X., W. Market and M. Kirchgessner. 1993. Optimal supply of a-amino nitrogen for growing pigs. 2. Communication on balance studies to reduce N excretion. J. Anim. Physiol. and Anim. Nutr. 70:196.

Roth, Von F.X., J. Fickler and M. Kirchgessner. 1994. N-balance of piglets as related to the omission of individual non-essential amino acids from the diet. 2. Communication on the importance of non-essential amino acids for protein retention. J. Anim. Physiol. and Anim. Nutr. 72:215.

Russell, L.E., G.L. Cromwell, and T.S. Staly. 1983. Tryptophan, threonine, isoleucine and methionine supplementation of a 12% protein, lysine-supplemented, corn-soybean meal diet for growing pigs. J. Anim. Sci. 56:1115.

Russell, L.E., B.J. Kerr, and R.A. Easter. 1987. Limiting amino acids in on 11% crude protein corn-soybean meal diet for growing pigs. J. Anim. Sci. 65:1266.

Spiekers, H., K.H. Grunewald, C. Seiwert, R. Struth, and E. Niess. 1991. Reduction of N-excretion of piglets and fattening pigs by feeding synthetic amino acids. Agribiol. Res. 44:235.

Stables, N.H.J. and J.R. Carr. 1979. Growth and nitrogen balance studies with growing pigs fed on diets containing normal or opaque-2 maize, meat and bone meal, and synthetic amino acids. N. Z. Journal of Agricultural Research. 19:311.

Thaler, R.C., G.W. Libal and R.L. Wahlstrom. 1986. Effect of lysine levels in pig starter diets on performance to 20 kg and on subsequent performance and carcass characteristics. J. Anim. Sci. 63:139.

Tokach, M.D., J.L. Nelssen, and G.L. Allee. 1989. Effect of protein and(or) carbohydrate fractions of dried whey on performance and nutrient digestibility of early-weaned pigs. J. Anim. Sci. 67:1307.

Wang, T.C. and M.F. Fuller. 1989. The optimum dietary amino acid pattern for growing pigs. Br. J. of Nutr. 62:77.

Yen, H.T., D.J.A. Cole, and D. Lewis. 1986. Amino acid requirements of growing pigs. Anim.Prod. 43:155.

CHAPTER III

EFFECT OF INCREASING LEVEL OF DIETARY WHEY PROTEIN CONCENTRATE (77 % CP) AS A LYSINE SOURCE ON PIG PERFORMANCE DURING PHASE 1 OF THE NURSERY PERIOD

M. E. Davis, B. Z. de Rodas, C. V. Maxwell, and J. Chung
Department of Animal Science, Oklahoma State University, Stillwater

ABSTRACT

Weanling pigs averaging 6 kg BW and 21 d of age were fed a diet containing whey protein concentrate (WPC) to determine the dietary lysine level that maximized gain and feed efficiency in Phase 1 (d 0 to 14 postweaning) nursery pigs. Two experiments involving 12 pens of 6 pigs each were conducted using a total of 144 pigs. Each pen was fed one of four dietary treatments formulated to contain 1.15%, 1.30%, 1.45%, and 1.60% total lysine by substituting WPC for corn starch and sucrose. All four diets contained 20% dehydrated whey, 6.6% select menhaden fish meal, 3.5% spray-dried plasma protein, 1.5% spray-dried blood meal, and 2.7% soy protein concentrate and were fed from d 0 to 14 postweaning. Lactose was added so that dietary levels were maintained at 18% in all four diets. To monitor any carryover effect from diets fed during phase 1, all pigs were fed a common Phase 2 (d 14 to 28 postweaning) diet containing a total lysine level of 1.35%, and a common Phase 3 (d 28 to 42 postweaning) diet containing a lysine level of 1.15%. Average daily gain (ADG), average daily feed intake (ADFI), and gain:feed (G/F) were assessed weekly. Average daily gain and G/F increased linearly ($P < .002$) with increasing level of dietary lysine from d 0 to 7. Similarly, increasing dietary lysine resulted in a linear ($P < .002$) increase in ADG and G/F from d 7 to 14 and d 0 to 14, but subsequent performance was not affected ($P > .10$) by previous Phase 1 diets during Phases 2 or 3. Average daily gain and

G/F increased linearly (P < .002) during the overall 42 d experimental period. Average daily feed intake did not differ (P > .10) during any phase of the study. These data indicate that the dietary lysine requirement for maximum gain and feed efficiency of Phase 1 nursery pigs is at least 1.60% when WPC serves as the lysine source.

INTRODUCTION

Concern over nitrogen excretion from swine waste has prompted interest in the use of synthetic amino acids as a means to reduce this contaminant by allowing diet formulation to better provide the pig's protein requirement. Substituting synthetic amino acids for a portion of the expensive complex protein ingredients often utilized in nursery pig rations results in a reduction in nitrogen excretion which is often excessive when natural protein sources are used to balance for the most limiting amino acid.

Several reports have suggested that NRC's (1988) lysine recommendation for 5-15 kg pigs may be too low. Mitchell, Jr. et al. (1965) conducted an experiment to determine the lysine requirement of 5 kg weanling pigs. They found the lysine needs of pigs at this stage of production to be between 1.24% and 1.34% of the diet based on weight gain of the animals.

Lewis et al. (1981) evaluated the lysine requirement of 5 kg pigs fed corn-soybean meal diets. Weight gain and feed efficiency improved up to 1.25% lysine but decreased after 1.35% of the diet. Pollmann et al. (1983) obtained similar results when 3-4 week old weaned pigs were fed corn-soybean meal diets.

Though many studies have been conducted to determine the lysine requirement of pigs in the postweaning stage of production, agreement as to the optimum level of lysine needed has not been reached. This variation in results suggests performance drives the pig's lysine requirement, meaning pigs with higher rates of gain and lean deposition may require more lysine than marginally performing pigs. The NRC (1988) currently recommends 1.15% lysine in the diets of weanling pigs. As pigs gain faster and deposit leaner tissue, additional lysine may be needed to reach full production potential.

Increased gain may be one of the explanations for the positive response of segregated early-weaned pigs to additional dietary lysine. Studies conducted recently at Kansas State University with segregated early weaned pigs suggest lysine requirements for the young pig may be much higher than NRC recommends. Average daily gain and G/F increased when pigs weighing less than 5 kg were fed 1.70% lysine and pigs weighing 5 to 7 kg were fed between 1.50% and 1.60% lysine (Owen et al., 1994). This leads to the conclusion that the recommended NRC level for the 5 kg pig needs to be reevaluated. Therefore, the objective of this study was to determine the dietary lysine requirement of weanling pigs during Phase 1 of the nursery period using WPC as the amino acid source.

MATERIALS AND METHODS

Two trials involving a total of 144 pigs (each trial with 72 pigs) averaging 6 kg BW and 21 d of age were conducted to evaluate the effect of increasing dietary lysine on pig gain and feed efficiency during Phase 1 (d 0 to 14, postweaning) of the nursery period. Pigs within each trial were allotted into three groups (blocks) based on initial BW. Pigs within each weight group were divided into four equal subgroups (six pigs per subgroup, or pen) in each of the two trials, and were stratified based on litter and sex. One of four dietary treatments was randomly assigned to each pen within block. Each dietary treatment was fed to three pens in each trial, resulting in a total of six pens per treatment in the two trials.

Experimental diets fed during Phase 1 (Table 3.1) were formulated by substituting WPC for cornstarch and sucrose to obtain dietary lysine levels of 1.15%, 1.30%, 1.45%, and 1.65% (Table 3.2). From d 0 to 14 postweaning, all four diets contained 20% dehydrated whey, 6.6% select menhaden fish meal, 3.5% spray-dried plasma protein, 1.5% spray-dried blood meal, and 2.7% soy protein concentrate. Whey protein concentrate varied in the diets from 0% in the control diet (1.15% lysine) to 9.55% in the diet containing the highest level of lysine (1.60%). Methionine was added to meet ideal protein ratios according to Chung and Baker (1992). Lactose, calcium, and phosphorus levels were maintained constant in all four diets at 18%, .93%, and .80%, respectively (Table 3.2). All pigs were fed a common Phase 2 diet (1.35% lysine) from d 14 to 28 and a common Phase 3 diet (1.15% lysine) from d 28 to 42 to monitor any carryover effect from treatment diets fed during the first two weeks of the experiment. A sample of each treatment diet fed during Phase 1 was taken for crude protein and amino acid analysis. Samples were analyzed by Experiment Station Chemical Laboratories (University of Missouri-Columbia).

Pigs were housed in elevated pens (1.14m x 1.5m) with woven wire flooring in an environmentally controlled nursery. Temperature was maintained initially at 30°C and decreased by 1°C weekly. Each pen was equipped from one nipple waterer and a five-hole feeder with feed and water available to all pigs on an ad libitum basis. Weight gain and feed intake were recorded weekly and ADG, ADFI, and G/F were calculated.

The data were analyzed as a randomized complete block design (Steel and Torrie, 1980) with pen as the experimental unit. Blocks were based on initial body weight. The analysis of variance was performed using GLM procedure of SAS (1988). The data from both trials were combined after testing the variances for homogeneity. Trial, block, treatment, trial*block, trial*treament, block*treament, and trial*block*treatment interaction effects were evaluated in the statistical model. However, the two-way interactions were deleted for lack of significance ($P < .25$). Orthogonal polynomials were used to test for linear, quadratic, and cubic effects.

RESULTS

The effect of increasing lysine level on ADG, ADFI, and G/F is shown in Table 3.3 and the results from amino acid analysis of the four treatment diets fed during Phase 1 are shown in Table 3.4. From d 0 to 7 postweaning, ADG and G/F increased linearly ($P < .002$) as dietary lysine level increased with the greatest ADG and G/F at 1.60% dietary lysine. Average daily gain of pigs fed the highest level of lysine was 295.45 g compared to 209.09 g for pigs fed the control diet with the lowest level of lysine, and pigs fed 1.60% lysine gained 1.18 kg for every kg of feed consumed as compared to .87 for pigs fed 1.15% dietary lysine. Pigs fed 1.60% lysine grew 41% faster and gained 36% more per kg of feed than pigs fed 1.15% lysine during the first week of the study. Feed intake was not significantly affected by dietary lysine level.

During d 7 to 14 and for the entire 14-d postweaning period, ADG and G/F continued to increase linearly ($P < .002$) as dietary lysine level increased. Average daily gain was 459.09 g for pigs fed 1.60% lysine from d 7 to 14 compared to 345.45 g for pigs fed 1.15% dietary lysine, and pigs fed 1.60% lysine during this period gained .92 kg for every kg of feed consumed while pigs fed 1.15% lysine gained only .69 kg per kg of feed. During the entire 14-d postweaning period, ADG was 377.27 g compared to 277.27 g for pigs fed 1.15% dietary lysine. Pigs fed 1.60% lysine during the two-week Phase 1 period gained 1.05 kg for each kg of feed consumed while pigs fed 1.15% gained .78 kg for every kg of feed. Pigs fed 1.60% dietary lysine grew 33% faster and gained 36% more efficiently per kg of feed than pigs fed 1.15% dietary lysine from d 7 to 14 postweaning, while pigs fed 1.60% dietary lysine during the entire 14-d postweaning period had 36% faster growth and were 35% more efficient in converting feed to whole body weight gain than those fed 1.15% dietary lysine. Average daily feed intake was not affected ($P > .10$) by dietary lysine level during d 7 to 14 postweaning, or during the entire 14-d period.

Diets fed during Phase 1 (d 0 to 14 postweaning) had no effect ($P > .10$) on growth performance during Phase 2 (d 14 to 28 postweaning) and Phase 3 (d 28 to 42 postweaning). However, during the overall 42 d experimental period a linear ($P < .002$) increase in ADG and G/F was observed with increasing dietary lysine level in Phase 1. Average daily gain during the overall 42 d experimental period was 490.91 g for pigs fed 1.60% during Phase 1 compared to 445.45 g for those fed 1.15% dietary lysine, and pigs fed 1.60% dietary lysine gained .76 kg for every kg of feed consumed compared to .67 kg gained per kg of feed consumed for pigs fed 1.15% lysine. Pigs initially fed 1.60% lysine during phase 1 grew 11% faster and were 13%

more efficient in converting feed to whole body gain over the entire experiment than those fed 1.15% dietary lysine during Phase 1.

DISCUSSION

Increasing dietary lysine level by addition of WPC during the first two weeks postweaning resulted in improved ADG and G/F, but had no impact on ADFI. During Phase 1 of the experiment ADG and G/F of pigs fed the highest level of lysine was improved by 36% and 35%, respectively. Similarly during the overall 42 d experiment, pigs fed the highest level of lysine showed an 11% improvement in ADG and a 13% improvement in G/F compared to pigs fed the control diet in the overall trial. Several reports show that increasing dietary lysine improves ADG and feed efficiency (G/F). Lewis et al. (1981) found lysine addition improved ADG and G/F in 5 kg pigs, with the greatest improvement in performance found between the levels of 1.15% and 1.25% lysine. Martinez and Knabe (1990) reported similar findings with 6 kg pigs where optimum performance was observed between 1.10% and 1.20% lysine. An additional study by Mitchell, Jr. et al. (1965) found the dietary lysine requirement of 5 kg pigs to be between 1.24% and 1.34% based on weight gain.

These studies confirm that the NRC (1988) may have underestimated the lysine requirement of the young pig. They do not, however, indicate that feeding weanling pigs lysine levels as high as those fed in the current experiment improves ADG and G/F. This may be due to the fact that animals in the previous studies were fed corn-soybean meal diets. The diets in this present study contained no soybean meal since it has been shown that weanling pigs do not utilize grain-soybean diets efficiently (Pals and Ewan, 1978).

Protein from milk sources such as whey provide a feed source that is much better suited to the needs of the young pig. Several reports agree with the findings of this study that WPC serves as an excellent protein source for young pigs. Cieslak et al. (1986) conducted a study to assess the value of liquid WPC relative to corn-soybean meal diets fed to growing pigs, and found growth rate to be higher per unit of crude protein when 50% of the dietary protein was supplied by WPC. A similar study by Cinq-Mars et al. (1986) fed 3 to 4 week old pigs liquid WPC compared to a corn-soybean meal-fish meal control diet. Average daily gain was 33% higher when liquid WPC was used to replace either all or a portion of the fish meal in the control diet.

Improvements observed when lysine was increased in the diet by addition of whey is likely due to the lactose component of whey rather than due solely to increased lysine. For instance, Lepine et al. (1991) conducted a study to determine the response of weaned pigs to additional lysine by feeding corn-soybean meal diets with and without supplemental whey. Growth increased when the dietary lysine level was raised from 1.10% to 1.50% in pigs fed diets containing whey, but no improvement was observed in those pigs fed diets without supplemental whey.

Additional evidence exists to support the concept that improvement in pig performance may be due to some component of whey rather than an increase in dietary lysine level. Tokach et al. (1989) conducted a study to determine whether the lactalbumin (the protein component) or lactose (the carbohydrate component) portion of whey was responsible for improvement in animal performance. They found that ADG and feed efficiency were improved when whey or either of the whey components were added to the diet. Improvements were similar between addition of whey, lactalbumin, or lactose, suggesting each has an equal impact on improvement of gain and efficiency of weanling pigs. A later study conducted by Mahan (1992) found that addition of lactalbumin and cornstarch to a corn-soybean meal diet did not improve pig performance, while addition of lactose and amino acids did. Their results indicate the improvement in pig growth and efficiency is most likely due to the lactose component of whey. However, in our study lactose was added to maintain a dietary level 18% in all experimental diets which may suggest that component(s) other than lactose are responsible for this improvement in performance. Additionally, an available carbohydrate source rather than lysine, may be the most limiting factor in the diet of the weaned pig.

IMPLICATIONS

The results of this experiment confirm the implication that NRC's (1988) recommendation for the lysine needs of the weaned pig are inadequate. Addition of dietary lysine from WPC improved ADG and G/F of 6.0 kg pigs weaned at 21 d of age. The parameters of this study do not allow for an estimation of the pigs' lysine requirement since maximum performance was observed at the highest lysine level (1.60%) of the diet. The results do indicate that the NRC's (1988) lysine recommendation for the weanling pig needs to be reevaluated.

Table 3.1. Composition of experimental diets with varying levels of lysine achieved by addition of whey protein concentrate.[a]

	Phase 1, lysine %				Phase 2	Phase 3
Ingredient,%	1.15	1.30	1.45	1.60		
Yellow corn, ground	35.55	35.55	35.55	35.55	55.075	68.97
Lactose	4.65	4.20	3.74	3.30	10.00	-
Dehydrated whey	20.00	20.00	20.00	20.00	-	-
Soybean meal (48% CP)	-	-	-	-	22.25	27.50
Soybean oil	4.00	4.00	4.00	4.00	-	-
Steam-rolled oats	10.00	10.00	10.00	10.00	-	-
AP-301[b]	1.50	1.50	1.50	1.50	2.00	-
Menhaden fish meal	6.57	6.57	6.57	6.57	5.00	-
Soy protein concentrate	2.67	2.67	2.67	2.67	-	-
AP-920[c]	3.50	3.50	3.50	3.50	-	-
Micro curb	-	-	-	-	.10	-
Lysine, HCl	-	-	-	-	.10	.15
Whey Protein Concentrate (77% CP)	-	3.19	6.38	9.55	-	-
Ethoxyquin	.03	.03	.03	.03	.03	-
DL-Methionine	.09	.10	.08	.09	.12	-
Neoterramycin[d]	1.00	1.00	1.00	1.00	-	-
Copper Sulfate	.07	.07	.07	.07	.05	.08
Calcium carbonate	-	-	-	-	.27	.60
Vitamin-mineral premix[e]	.38	.38	.38	.38	.25	.25
Dicalcium phosphate	1.39	1.34	1.25	1.19	1.43	1.90
Cornstarch	4.00	2.65	1.34	-	-	-
Sucrose	4.00	2.65	1.34	-	-	-
Salt	.20	.20	.20	.20	.30	.42
Flavor	.10	.10	.10	.10	-	-
Zinc oxide	.30	.30	.30	.30	.30	-
Threonine	-	-	-	-	.05	-
Tylan40-Sulfa	-	-	-	-	.125	.125

[a] Diets were formulated to contain .92% Ca, .81% P, and 18% lactose during Phase 1, 1.35% lysine. .80% Ca, and .70% P during Phase 2, and 1.15% lysine, .80% Ca, and .71% P in Phase 3.

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

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

[d] Contained 10 g of Neomycin and 5 g of oxytetracycline per lb. of product.

[e] 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 kilogram of feed during Phase 1, and 6,600 IU of vitamin A, 660 IU of vitamin D_3, 12.8IU of vitamin E, 5.5 mg of vitamin D_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, 150 mg of Fe, 15 mg of Zn, and .37 mg of I per kilogram of feed during Phase 2.

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

Table 3.2. Calculated compositions of crude protein, lactose, amino acids, calcium, and phosphorus in diets containing whey protein concentrate as the amino acid source.

	Treatments (lysine %)			
Calculated Composition	1.15	1.30	1.45	4.60
Crude Protein, total	17.25	19.72	22.16	24.61
Lactose	18.00	18.00	18.00	18.00
Calcium	.92	.92	.92	.92
Phosphorus	.81	.81	.81	.81
Lysine	1.15	1.30	1.45	1.60
Tryptophan	.22	.27	.32	.37
Threonine	.78	.91	1.04	1.17
Methionine + Cystine	.68	.78	.86	.96
Valine	.99	1.11	1.24	1.37
Isoleucine	.68	.81	.94	1.06
Phenylalanine	.86	.96	1.05	1.15
Tyrosine	.59	.59	.59	.59
Leucine	1.70	1.85	2.01	2.16
Arginine	.95	1.00	1.05	1.11
Histidine	.51	.57	.62	.67

Table 3.3. Performance of pigs fed increasing levels of dietary lysine from whey protein concentrate during Phase 1 of the nursery period.

	Lysine level, %			
Item	1.15	1.30	1.45	1.60
d 0 to 7				
ADG, g[b]	218.18	222.73	245.45	295.45
ADFI, g	240.91	231.82	231.82	2505
Gain:feed[b]	.87	.96	1.04	1.18
d 7 to 14				
ADG, g[b]	345.45	395.45	431.82	459.09
ADFI, g	500.00	513.64	518.18	504.55
Gain:feed[b]	.69	.77	.83	.92
d 0 to 14				
ADG, g[b]	277.27	309.09	336.36	377.27
ADFI, g	368.18	372.73	377.27	377.27
Gain:feed[b]	.78	.87	.93	1.05
d 14 to 28				
ADG, g	486.36	477.27	490.91	486.36
ADFI, g	704.55	704.55	731.82	695.45
Gain:feed	.69	.68	.67	.69
d 28 to 42				
ADG, g	568.18	595.45	604.55	613.64
ADFI, g	1050.00	1100.00	1154.55	1131.82
Gain:feed	.55	.54	.52	.54
d 0 to 42				
ADG, g[b]	445.45	459.09	477.27	490.91
ADFI, g	709.09	727.27	754.55	736.36
Gain:feed[b]	.67	.70	.71	.76

[a] Data are means of 6 pens of 6 pigs each. Pigs averaged 6 and 25.6 kg at trial initiation and termination, respectively.

[b] Linear effect of increasing dietary lysine ($P < .002$).

Table 3.4. Amino acid analysis of experimental diets fed during Phase 1.[a]

	Treatments			
Amino acids	1	2	3	4
Crude protein	16.97	19.01	22.05	28.39
Lysine	1.05	1.28	1.53	1.71
Tryptophan	0.22	0.27	0.34	0.37
Threonine	0.72	0.85	1.00	1.12
Methionine	0.38	0.44	0.49	0.53
Cysteine	0.33	0.40	0.47	0.52
Valine	0.94	0.95	1.20	1.28
Isoleucine	0.62	0.67	0.89	0.98
Phenylalanine	0.77	0.84	0.97	1.04
Tyrosine	0.50	0.57	0.67	0.78
Leucine	1.52	1.78	2.16	2.42
Arginine	0.85	0.89	1.01	1.04
Histidine	0.49	0.52	0.60	0.63
Glycine	0.79	0.81	0.89	0.91
Glutamic acid	2.40	2.76	3.21	3.52
Serine	0.67	0.81	0.89	0.99
Aspartic acid	1.51	1.75	2.08	2.31
Proline	0.95	1.07	1.21	1.31
Hydroxyproline	0.08	0.08	0.08	0.08
Ornithine	0.01	0.01	0.01	0.01
Alanine	0.98	1.09	1.24	1.34

[a] Values are the determined protein and amino acid composition of diets used in this study. Samples were analyzed by Experiment Station Chemical Laboratories, University of Missouri-Columbia.

LITERATURE CITED

Chung, T.K. and D.H. Baker. 1992. Ideal amino acid pattern for 10-kilogram pigs. J. Anim. Sci. 70:3102.

Cieslak, D.G., N.J. Benevenga, and R.H. Grummer. 1986. The evaluation of fresh sweet liquid whey as a protein supplementation to maize for growing pigs. Animal Feed Science and Technology. 14:171.

Cinq-Mars, D., G. Belanger, B. Lachance, and G.J. Brisson. 1986. Performance of early-weaned piglets fed diets containing various amounts of whey protein concentrate. J. Anim. Sci. 63:145.

Lepine, A.J., D.C. Mahan and Y.K. Chung. 1991. Growth performance of weanling pigs fed corn-soybean meal diets with or without whey at various L-lysine-HCl levels. J. Anim. Sci. 69:2026.

Lewis, A.J., E.R. Peo, Jr., B.D. Moser and T.D. Crenshaw. 1981. Lysine requirement of pigs weighing 5 to 15 kg fed practical diets with and without added fat. J. Anim Sci 51:361.

Mahan, D.C. 1992. Efficacy of dried whey and its lactalbumin and lactose components at two dietary lysine levels on postweaning pig performance and nitrogen balance. J. Anim. Sci. 70:2182.

Martinez, G.M. and D.A. Knabe. 1990. Digestible lysine requirement of starter and grower pigs. J. Anim. Sci. 68:2748.

Mitchell, Jr., J.R., D.E. Becker, A.H. Jensen, H.W. Norton, and B.G. Harmon. 1965. Lysine need of swine at two stages of development. J. Anim. Sci. 24:409.

NRC. 1988. Nutrient Requirements of Swine (9th Ed..) National Academy Press, Washington, DC.

Owen, K.Q., J.L. Nelssen, R.D. Goodband, M.D. Tokach, B.T. Richert, K.G. Friesen, J.W. Smith, II, J.R. Bergstrom, and S.S. Dritz. 1994. Dietary lysine requirements of segregated early-weaned pigs. Kansas State University Swine Day. pp. 37-41.

Pals, D.A. and R.C. Ewan. 1978. Utilization of the energy of dried whey and wheat middlings by young swine. J. Anim. Sci. 46:402.

SAS. 1988. SAS User's Guide: Statistics. SAS Inst., Inc., Cary, NC.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics. pp. 197-201. McGraw-Hill, Inc., New York.

Tokach, M.D., J.L. Nelssen, and G.L. Allee. 1989. Effect of protein and(or) carbohydrate fractions of dried whey on performance and nutrient digestibility of early-weaned pigs. J. Anim. Sci. 67:1307.

CHAPTER IV

DETERMINATION OF THE EFFICACY OF AMINO ACID SUPPLEMENTATION FOR WHEY PROTEIN CONCENTRATE IN DIETS FOR CONVENTIONALLY WEANED PIGS

M.E. Davis, B.Z. de Rodas, C.V. Maxwell, E. Broekman, and J. Chung

Department of Animal Science, Oklahoma State University, Stillwater

ABSTRACT

Weanling pigs averaging 6.3 kg and 21 days of age were fed one of five dietary treatments to determine the extent to which amino acids can be substituted for a natural protein source in the diet without affecting pig performance. Treatments were arranged in a 2 x 2 factorial with a negative control. The negative control diet (Treatment 1) was formulated to contain 1.01% available lysine. The factorially arranged treatments consisted of two lysine levels of 1.22% and 1.43% formulated using amino acids and whey protein concentrate (WPC). Treatments 2 and 3 were formulated using WPC as a supplemental source of amino acids, while in Treatments 4 and 5 whey protein concentrate was replaced with a mixture of amino acids. All five diets contained 20% dried whey, 6.6% select menhaden fishmeal, 3.5% spray-dried plasma protein, 1.5% spray-dried blood meal, and 2.7% soy protein concentrate and were fed from d 0 to 14 postweaning. Lactose was added so that dietary levels were maintained at 18% in all five diets. All pigs were fed common phase 2 (d 14 to 28 postweaning) and phase 3 (d 28 to 42 postweaning) diets to monitor any carryover effects from the treatments fed during phase 1. Average daily gain, ADFI, and G/F were assessed weekly and blood samples were taken via vena cava puncture on d 14 following phase 1 treatment to determine blood urea nitrogen (BUN) concentrations. During d 0 to 7, d 7 to 14, and d 0 to 14, ADG was similar for pigs fed the WPC

or the synthetic amino acid diet at the lower level of protein supplementation (1.22% available lysine; Treatment 2 vs Treatment 4). Average daily gain in pigs fed diets supplemented with WPC (Treatments 2 and 3) was greater ($P < .05$) than those fed the negative control diet (Treatment 1). During d 7 to 14 and d 0 to 14, average daily gain in pigs fed the highest level of protein supplementation (1.43% available lysine) using synthetic amino acids was lower ($P < .05$) than those fed the negative control diet. Gain:feed during d 0 to 7 and d 0 to 14 was similar in pigs fed the lower level of protein supplementation from either WPC or synthetic amino acids (1.22% available lysine; Treatment 2 vs Treatment 4). Gain:feed was greater ($P < .05$) in pigs fed the higher level of protein supplementation (1.43% available lysine) when WPC was used as the amino acid source compared to those fed diets containing synthetic amino acids and the negative control diet. The synthetic amino acid diet fed at the high lysine level resulted in pigs with similar G/F as those fed the negative control diet. Blood urea nitrogen concentrations were lower ($P < .05$) in pigs fed diets containing synthetic amino acids (Treatments 4 and 5) than for pigs fed diets containing WPC (Treatments 2 and 3) regardless of the lysine level fed (1.22% or 1.43%). Pigs fed the WPC diet at the higher lysine level (Treatment 3) had greater ($P < .05$) BUN concentrations than pigs fed the lower lysine level containing WPC, the diets formulated with synthetic amino acids, and the negative control diet. These results indicate that substituting high levels of amino acids for a natural protein source in the diet may be detrimental to growth and efficiency of weanling pig performance.

INTRODUCTION

Providing a weaned pig's protein needs using high quality, natural feed ingredients results in expensive diets with excesses of many dispensable and indispensable amino acids. Supplementation of synthetic amino acids for expensive protein sources in nursery pig diets offers the potential to reduce feed costs and lower some of these amino acid excesses. The question remains whether synthetic amino acid diets can result in the same pig performance as diets formulated using quality, nutrient dense ingredients.

Research conducted at Kansas State University with early weaned pigs found ADG and feed efficiency improved when synthetic lysine and an essential amino acid mixture were added to obtain 1.70% dietary lysine (Owen et al., 1994). Lepine et al. (1991) also observed an increase in growth rate when L-lysine hydrochloride was used to elevate the lysine level of the diet up to 1.50%. These studies suggest there were no detrimental effects on pig performance when synthetic amino acids are used to meet the pigs' protein requirement.

However, other experiments exposed problems associated with feeding high levels of synthetic amino acids to pigs. Stables and Carr (1979) found that feed refusals were more common when lysine and/or methionine were added to corn diets, but returned to normal with the addition of tryptophan. This indicates that addition of lysine without tryptophan causes an amino acid imbalance resulting in depressed feed intake. In addition, Corley and Easter (1980) fed growing pigs a 10% crude protein diet supplemented with lysine and tryptophan and observed inferior growth rate and feed efficiency when compared to a 16% crude protein diet.

Average daily gain and G/F increased linearly as lysine increased from 1.15% to 1.60% of the diet in the previous experiment. The question remains whether or not similar performance can be obtained if all or a portion of the WPC is replaced by a mixture of synthetic amino acids. Therefore, the objective of this study is to 1) confirm the response of nursery pigs fed a nutrient dense Phase 1 diet using WPC as the amino acid source to elevate dietary lysine levels, and 2) to determine if similar growth and efficiency can be obtained when synthetic amino acids are used to substitute for a portion of the amino acids in WPC.

MATERIALS AND METHODS

A total of 120 pigs weaned at approximately 21 d of age were allotted to five dietary treatments (Table 4.1) arranged as a 2 x 2 factorial design with a negative control. Each diet was fed to four pen replicates of six pigs per pen. The negative control diet (Treatment 1) was a nutrient dense diet containing 1.01% available lysine and no WPC. The factorially-arranged treatments consisted of two dietary lysine levels (1.22% and 1.43% available lysine) in nutrient-dense diets containing WPC as a source of amino acids (Treatments 2 and 3) or with the WPC component replaced by an amino acid mixture (Treatments 4 and 5). The lysine levels were achieved by increasing the amount of WPC or crystalline amino acids at the expense of cornstarch and sucrose.

Diets were formulated on an available amino acid basis using availability values listed in Table 4.2 and 4.3. Dietary amino acid levels were supplemented with synthetic amino acids to meet the ideal ratios according to Chung and Baker (1992) in reference to the dietary lysine level. Experimental diets were fed from d 0 to 14 (Phase 1), after which a common Phase 2 and Phase 3 diet was fed for two weeks each to all pigs to monitor any carryover effect of the diets fed during Phase 1. A sample of each diet was obtained for crude protein and amino acid analysis.

The trial was conducted in an environmentally controlled nursery with temperature maintained initially at 30°C and decreased by 1°C weekly. Pigs were housed in elevated pens (1.14m x 1.5m) with woven wire flooring and had ad libitum access to one nipple waterer and a 4-hole feeder. Pig weight and feed consumption were recorded weekly and ADG, ADFI, and G/F were calculated. A blood sample from each pig was obtained via vena cava puncture on d 14 of the trial. Serum was analyzed for urea nitrogen concentration using Roche® reagents for blood urea nitrogen (Roche Diagnostic Systems, Sommerville, NJ).

Before combining both trials, the variances were tested to ensure homogeneity. The data were analyzed as a randomized complete block design (Steel and Torrie, 1980) with a 2 x 2 factorial arrangement of treatments and a negative control. Pen was considered the experimental unit. The analysis of variance was performed using the GLM procedure of SAS (1988). The final model included block, lysine source, lysine level, and lysine source*lysine level. The replicate*lysine source, replicate*lysine level, and replicate*lysine source*lysine level were deleted from the initial model for lack of significance (P > .30). Specific differences between treatment means were determined by *t*-test when the interaction of lysine source and lysine level was significant. In addition, comparison of the negative control vs. other diets were made.

RESULTS

The effect of increasing lysine level from two amino acid sources on ADG, ADFI, and G/F is shown in Table 4.5, and the results from amino acid analysis of the five treatment diets fed during phase 1 are shown in Table 4.6. There were some problems with the health status of the pigs during this experiment. Of nine total pigs treated during the 42d experiment, four pigs died and 1 was removed from trial because of inability to recover when treatment (6cc of penicillin containing Benzathene) was administered,. Diagnostic analysis of those pigs removed from trial revealed the presence of *Streptococcus suis*.

During d 0 to 7, d 7 to 14, and d 0 to 14, ADG was similar in pigs fed the WPC diet or the synthetic amino acid diet at the lower level of protein supplementation (1.2% available lysine; Treatment 2 vs. Treatment 4). However, at the higher level of protein supplementation (1.43% available lysine), there was an increased ADG when WPC was used as the amino acids source and a reduction in ADG when synthetic amino acids were used. Average daily gain in pigs fed the highest level of lysine using synthetic amino acids tended to be lower than that observed in pigs fed the negative control diet during d 7 to 14 and d 0 to 14 ($P < .10$). This different response to amino acid supplementation from the two sources (WPC or synthetic amino acids) resulted in a significant ($P < .05$) lysine source x lysine level interaction during d 0 to 7, d 7 to 14, and d 0 to 14.

Gain:feed during d 0 to 7 and d 0 to 14 was similar in pigs fed the lower level of protein supplementation from either WPC or synthetic amino acids (1.22% available lysine; Treatment 2 vs Treatment 4). However, at the higher level of protein supplementation (1.43% available lysine) G/F was greater ($P < .05$) when WPC was used as the amino acid source, while the synthetic amino acid diet resulted in pigs with similar G/F as those fed the negative control diet.

The different response to amino acid supplementation from the two sources (WPC or synthetic amino acids) resulted in a significant ($P < .05$) lysine source x lysine level interaction during d 0 to 7 and d 0 to 14.

Blood urea nitrogen concentrations were lower ($P < .05$) in pigs fed diets containing synthetic amino acids (Treatments 4 and 5) than for pigs fed diets containing WPC (Treatments 2 and 3) regardless of the lysine level fed (1.22% or 1.43%). Blood urea nitrogen concentrations in pigs fed the synthetic amino acid diets were actually lower ($P < .05$) than that observed in pigs fed the negative control diet. Pigs fed the WPC diet at the higher lysine level (Treatment 3) had greater ($P < .05$) BUN concentrations than pigs fed the lower lysine level containing WPC, the diets formulated with synthetic amino acids, and negative control diet.

DISCUSSION

Nursery pigs in this study did not respond as well to elevated lysine levels obtained by increasing WPC and as did pigs in a previous experiment (Davis et al., 1996). This was probably due to the poor health status of pigs in the current experiment compared to those pigs in the earlier trial. This makes the data difficult to interpret since the differences among treatments or the lack of differences could have been influenced by the pigs' health status.

However, it is apparent from the data that pigs fed the synthetic amino acid diet containing the highest level of lysine had poorer ADG and G/F as well as decreased feed intake. Whether intake inhibition was due to impalatability of synthetic amino acids or to a dietary amino acid imbalance is uncertain.

Blood urea nitrogen values were very low for the pigs fed the synthetic amino acid diets, indicating that these pigs may be receiving marginal amounts, or possibly deficient levels, of their required amount of dietary protein. Blood urea nitrogen was used as an indicator of amino acid utilization. When the limiting amino acid is at deficient levels, it restricts the use of other amino acids for protein synthesis. These surplus amino acids are used for urea synthesis thereby increasing BUN values. When the dietary level of the limiting amino acid increases, more amino acids are able to be used for protein synthesis and less amino nitrogen is synthesized into urea. Therefore, high BUN levels indicate an excess of amino acids in relation to the one most limiting, and low levels indicate fewer excesses of amino acids and a diet more closely balanced to the pigs ideal protein requirement.

Whey protein concentrate used to acquire the high lysine levels particularly in Treatment 3, contained many excesses of amino acids that were converted to urea. This resulted in pigs fed the high lysine diet containing WPC to have higher BUN values. Since the large amount of the natural protein source in the diet was reduced in Treatments 4 and 5 and synthetic amino acids were used to supplement the pigs' amino acid requirement on an ideal basis (Chung and Baker, 1992), the low BUN concentrations observed suggest a lowering of the catabolism of excess amino acids.

No attempt was made to keep the dietary treatments fed during Phase 1 isonitrogenous. Several reports suggest that pigs have a minimum crude protein requirement and will not respond to amino acid additions if nitrogen is limiting. Corley and Easter (1980) found that when a 10% CP amino acid supplemented diet was fed to growing pigs, growth and efficiency were inferior to performance of pigs fed 16% CP unsupplemented diets. Yet, when pigs were fed a 12% CP amino acid-supplemented diet, performance was similar to those fed the 16% CP diet. Kephart and Sherritt (1990) fed growing pigs a control diet of corn-soybean meal formulated at 115% of the pigs' lysine requirement. The corn:soybean meal ratio of the control diet was altered to obtain a 10% CP diet supplemented with synthetic amino acids so that the lysine, tryptophan, threonine, isoleucine, methionine, and valine amounts were equivalent to the original diet. Pigs fed the 10% CP diets had lower gain and efficiency than those fed the control diet. The researchers suggest this may be due to the different rates of absorption of free amino acids added to the low protein diet and amino acids present in the intact proteins fed in the control diet.

A deficiency in non-essential nitrogen could be a plausible explanation for the poor performance observed in pigs fed the synthetic amino acid diets since the crude protein was much lower in Treatments 4 and 5 than in Treatments 1, 2, and 3. However, the CP content of Treatments 4 and 5 were 17.96% and 18.72%, respectively. Crude protein in these diets are not low enough to indicate an inadequate supply of non-essential nitrogen. Yet, Fickler et al. (1994) compared a chemically defined amino acid diet (formulated to contain ideal ratios of essential amino acids and a mixture of non-essential amino acids) and a control diet (a commonly fed diet containing grain, soybean meal, fish meal, and skim milk powder) to 10 kg pigs. Pigs fed the chemically defined diet experienced a 24% decrease in growth rate compared to the control pigs and had lower nitrogen retention. Fickler et al. (1994) concluded that the amount of dispensable amino acids should be raised in order to increase the amount of non-essential nitrogen available to the pigs and the pattern of indispensable amino acids should be improved before satisfactory growth and nitrogen retention could be realized. The problems in this study could be associated with a deficiency in the amount of non-essential nitrogen or an inaccurate assumption in the ideal amino acid pattern for the 5 kg pig.

IMPLICATIONS

The potential for synthetic amino acid use in swine diets has gained attention for their potential to reduce nitrogen excretion by lowering the amount of excess amino acids usually present when natural protein sources are used to meet the pig's lysine requirement. Though there has been some success when small additions of synthetic amino acids are used to replace 2% of the diet's natural protein source, there have been problems associated when higher levels are substituted. These results indicate that synthetic amino acid supplementation for WPC in weaned pig diets does not produce equal performance, and present the need for continued research to establish if a deficiency of non-essential nitrogen is the cause.

Table 4.1. Composition of experimental diets comparing dietary protein supplementation using whey protein concentrate and synthetic amino acids.

	Treatments						
	1	2	3	4	5	Phase 2	Phase 3
	Lysine, % (available basis)						
Ingredients	1.01	1.22	1.43	1.22	1.43	1.35	1.15
Corn, ground	35.52	35.52	35.52	35.52	35.52	55.075	68.97
Soy Protein Concentrate	2.67	2.67	2.67	2.67	2.67	-	-
Soybean meal, 48% CP	-	-	-	-	-	22.25	27.50
Lactose	4.65	3.97	3.29	4.65	4.65	10.00	-
Whey	20.00	20.00	20.00	20.00	20.00	-	-
AP-920	3.50	3.50	3.50	3.50	3.50	-	-
AP-301	1.50	1.50	1.50	1.50	1.50	2.00	-
Steam-rolled oats	10.00	10.00	10.00	10.00	10.00	-	-
Whey Protein Concentrate, 77% CP	-	4.80	9.60	-	-	-	-
Ethoxiquin	.03	.03	.03	.03	.03	.03	-
Lysine, HCl	-	-	-	.27	.54	.15	.15
Fish meal	6.57	6.57	6.57	6.57	6.57	5.00	-
Zinc Oxide	.30	.30	.30	.30	.30	.30	-
Neoterramysin[a]	1.00	1.00	1.00	1.00	1.00	-	-
Flavor	.10	.10	.10	.10	.10	-	-
Copper Sulfate	.07	.07	.07	.07	.07	.05	.08
Sucrose	3.99	2.00	-	3.63	3.22	-	-
Cornstarch	3.99	2.00	-	3.62	3.21	-	-
Vitamin TM Premix[b]	.38	.38	.38	.38	.38	.25	.25
Isoleucine	.03	-	-	.16	.30	-	-
Methionine	.08	.09	.08	.22	.34	.12	-
Threonine	.01	-	-	.15	.29	.05	-
Dicalcium Phosphate	1.39	1.30	1.19	1.40	1.39	1.43	1.90
Soy oil	4.00	4.00	4.00	4.00	4.00	-	-
Valine	-	-	-	-	.12	-	-
Micro curb	-	-	-	-	-	.10	-
Tylan40-Sulfa[c]	-	-	-	-	-	.125	.125
Tryptophan	.02	-	-	.06	.10	-	-
Calcium Carbonate	-	-	-	-	-	.27	.60
Salt	.20	.20	.20	.20	.20	.30	.42

[a] Contained 10 g of Neomycin and 5 g of oxytetracycline per lb. of product.

[b] 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 kilogram 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 D_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, 150 mg of Fe, 15 mg of Zn, and .37 mg of I per kilogram of feed during Phase 2.

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

Table 4.2. Calculated compositions of crude protein, lactose, amino acids, calcium, and phosphorus comparing dietary protein supplementation with whey protein concentrate or synthetic amino acids.

	Treatments						
	1	2	3	4	5	Phase 1	Phase 2
	Lysine, % (available basis)						
Calculated Composition	1.01	1.22	1.43	1.22	1.43	1.35	1.15
Crude Protein, total	17.30	20.95	24.63	17.96	18.72	20.62	19.32
Lactose	18.00	18.00	18.00	18.00	18.00	9.90	-
Calcium	.92	.92	.92	.92	.92	.80	.82
Phosphorus	.81	.81	.81	.81	.81	.70	.71
Lysine	1.01	1.22	1.43	1.22	1.43	1.35	1.15
Tryptophan	.18	.23	.30	.22	.26	.25	.25
Threonine	.66	.80	.96	.79	.93	.87	.77
Met + Cys	.60	.74	.86	.74	.86	.79	.66
Valine	.85	1.01	1.17	.85	.97	1.13	1.01
Isoleucine	.60	.73	.90	.73	.86	.82	.83
Phenylalanine	.72	.79	.86	.72	.72	1.03	.97
Tyrosine	.69	.76	.82	.69	.69	.69	.73
Leucine	1.51	1.80	2.10	1.51	1.51	1.92	1.82
Arginine	.84	.91	.98	.84	.84	1.26	1.31
Histidine	.47	.54	.62	.47	.47	.65	.52

Table 4.3a. Values (on a percentage basis) for apparent ileal digestibility of protein ingredients utilized in experimental diets.

	Amino Acids						
Ingredients	LYS	TRP	THR	MET	CYS	VAL	ILE
AP-301[a]	95	93	92	97	93	97	79
AP-920[b]	84	73	77	61	73	81	80
Corn, ground	68[c]	67[c]	69[c]	85[c]	77[c]	77[c]	77[c]
Fishmeal	87[c]	78[c]	81[c]	85[c]	71[c]	81[c]	83[c]
Soy Protein Conc.	88[d]	81[c,e]	85[d]	83[f]	78[f]	86[d]	90[d]
St. Rolled Oats	79[c]	80[c]	74[c]	82[c]	77[c]	82[c]	83[c]
Whey, dried	79[c]	81[c]	83[c]	93[c]	92[c]	89[c]	90[c]
Whey Prot. Conc.	94[g]	89[c]	80[c]	84[c]	90[c]	84[c]	86[c]

[a] Spray-dried blood meal source; Availability values provided by American Protein Corp., Ames, IA.
[b] Spray-dried plasma protein source; Availability values provided by American Protein Corp., Ames, IA.
[c] Availability values from Heartland Lysine , Inc., 1996. Chicago, IL.
[d] Availability values from an experiment by Sohn et al. (1994) using early-weaned pigs.
[e] Tryptophan value was not available for soy protein concentrate so availability of tryptophan in soybean meal (48%) from Heartland Lysine was used.
[f] Availability values from an experiment by Walker et al. (1986) using early-weaned pigs.
[g] Availability value from Land O'Lakes, Fort Dodge, IA.

Table 4.3b. Values (on a percentage basis) for apparent ileal digestibility of protein ingredients utilized in experimental diets.

	Amino Acids				
Ingredients	PHE	TYR	LEU	ARG	HIS
AP-301[a]	96	86	97	94	100
AP-920[b]	81	79	82	81	87
Corn, ground	80[c]	83[d]	85[c]	82[c]	79[c]
Fishmeal	81[c]	83[d]	85[c]	87[c]	83[c]
Soy Prot. Conc.	88[e]	87[e]	92[e]	90[e]	88[e]
St. Rolled Oats	86[c]	82[d]	84[c]	83[c]	83[c]
Whey, dried	83[c]	93[d,f]	94[c]	86[c]	94[c]
Whey Prot. Conc.	89[c]	93[d,g]	90[c]	88[c]	84[c]

[a] Spray-dried blood meal source; Availability values provided by American Protein Corp., Ames, IA.

[b] Spray-dried plasma protein source; Availability values provided by American Protein Corp., Ames, IA.

[c] Availability values from Heartland Lysine , Inc., 1996. Chicago, IL.

[d] Availability values from L. Lee Southern, Biokyowa Technical Review, 1991.

[e] Availability values from an experiment by Sohn et al. (1994) using early-weaned pigs.

[f] Tyrosine values for whey protein concentrate and dried whey were not available so dried skim milk value was used from L. Lee Southern, Biokyowa Technical Review, 1991.

[g] Availability value from Land O'Lakes, Fort Dodge, IA.

Table 4.4a. Total and available compositions of ingredients used in experimental diets.[a]

Amino Acids	AP-920 total	AP-920 avail	AP-301 total	AP-301 avail	WHEY total	WHEY avail	OATS total	OATS avail
LYS	6.90	5.80	9.00	8.55	.91	.72	.64	.51
TRP	1.30	1.20	1.20	1.12	.16	.13	.18	.14
THR	4.30	3.31	3.60	3.31	.80	.66	.56	.41
MET	.70	.43	.80	.78	.19	.18	.27	.22
CYS	1.80	1.31	.60	.56	.35	.32	.55	.42
VAL	5.20	4.21	9.20	8.92	.68	.61	.82	.67
ILE	2.00	1.60	.60	.47	.71	.64	.58	.48
PHE	4.80	3.99	7.10	6.82	.34	.28	.76	.65
TYR	4.00	3.16	2.20	1.89	1.14	1.06	.49	.40
LEU	7.40	6.07	13.40	13.00	1.23	1.16	1.19	1.00
ARG	4.50	3.65	4.00	3.76	.29	.25	1.13	.94
HIS	2.50	2.18	7.50	7.50	.20	.19	.45	.37

[a]Available compositions were calculated using the apparent ileal digestibility percentages from Table 2. Postscripts indicate the source of total composition values.

[b]Plasma protein source. Total composition values from American Protein Corp., Ames, IA

[c]Blood meal. Total composition values from American Protein Corp., Ames, IA

[d] Total composition values for dried whey and steam-rolled oats from Heartland Lysine, Inc., except tyrosine, which was obtained for each ingredient from L. Lee Southern, Biokyowa Technical Review, 1991.

Table 4.4b. Total and available compositions of ingredients used in experimental diets.[a]

	SPC[a]		CORN[b]		FISH MEAL[b]		WPC[c]	
Amino Acids	total	avail	total	avail	total	avail	total	avail
LYS	6.10	5.39	.26	.18	4.84	4.21	4.70	4.42
TRP	.57	.46	.08	.05	.57	.44	1.64	1.46
THR	3.85	3.28	.31	.21	2.71	2.20	4.05	3.24
MET	1.16	.96	.18	.15	1.81	1.54	1.20	1.01
CYS	1.06	.82	.19	.15	.61	.43	1.84	1.66
VAL	4.20	3.60	.43	.33	3.07	2.49	4.00	3.36
ILE	4.03	3.63	.31	.24	2.68	2.22	4.00	3.44
PHE	5.03	4.42	.41	.33	2.45	1.98	1.53	1.36
TYR	3.32	2.89	.38	.32	1.93	1.60	1.52	1.41
LEU	7.88	7.22	1.06	.90	4.54	3.86	6.90	6.21
ARG	7.07	6.39	.40	.33	3.86	3.36	1.60	1.41
HIS	2.38	2.10	.26	.21	1.45	1.20	1.76	1.48

[a] Soy protein concentrate. Total composition values from Sohn et Al., 1994. Tryptophan was not reported, so the value for soybean meal (48%) from Heartland Lysine, Inc. was used for its total composition.

[b] Total composition values for corn and fishmeal from Heartland Lysine, Inc., except tyrosine, which was obtained for each ingredient from L. Lee Southern, Biokyowa Technical Review, 1991.

[c] Whey protein concentrate. Total composition values from Land O'Lakes, Fort Dodge, IA.

Table 4.5. Performance of pigs fed whey protein concentrate vs. synthetic amino acids during Phase 1 of the nursery period.[a]

	Lysine % (available basis)				
	1.01	1.22	1.43	1.22	1.43
	Treatment				
Item	1	2	3	4	5
d 0 to 7					
ADG, g	189.54^{b}	229.07^{c,d}	251.10^{c,}	203.15^{b,d}	169.78^{b}
ADFI, g	250.13	268.27	256.28	246.89	243.00
Gain:feed	.77^{b,d}	.87^{b,c}	.98^{c}	.84^{b}	.70^{d}
d 7 to 14					
ADG, g	356.72^{b}	373.25^{b}	374.87^{b}	359.32^{b}	279.94^{c}
ADFI, g	484.06	475.63	455.22	464.29	429.30
Gain:feed	.75	.81	.82	.78	.65
d 0 to 14					
ADG, g	273.13^{b}	301.16^{b}	312.98^{b}	281.23^{b}	224.86^{c}
ADFI, g	367.09	371.95	355.75	355.59	336.15
Gain:feed	.76^{b,d}	.84^{b,c}	.90^{c,}	.81^{b,c}	.68^{d}
d 14 to 28					
ADG, g	460.73	480.01	381.02	475.96	436.27
ADFI, g	727.70	784.40	744.59	714.02	706.81
Gain:feed	.64	.63	.52	.67	.62
d 28 to 42					
ADG, g	545.45	584.98	617.38	567.00	615.28
ADFI, g	1003.47	1087.11	1111.63	1062.98	1090.85
Gain:feed	.54	.56	.55	.53	.57
d 0 to 42					
ADG, g	426.44	455.38	437.13	448.99	425.47
ADFI, g	699.42	747.82	737.32	710.86	711.27
Gain:feed	.65	.68	.66	.67	.62
BUN (mg/dl)	4.95^{b}	4.80^{b}	6.99^{c}	2.62^{d}	2.46^{d}

[a] LS means of 4 pens/treatment with 6 pigs/pen.

[b,c,d] Means in the same row with different subscripts differ (P<.05).

Lysine source * lysine level interaction (P < .05).

Table 4.6. Amino acid analysis of experimental diets fed during Phase 1.[a]

Amino acids	Treatments 1	2	3	4	5
Crude protein	17.06	20.54	24.14	17.89	18.50
Lysine	1.14	1.45	1.79	1.41	1.54
Tryptophan	.26	.31	.89	.30	.88
Threonine	.75	.92	1.14	.92	1.00
Methionine	.38	.47	.57	.55	.68
Cysteine	.36	.45	.58	.88	.36
Valine	.94	1.12	1.31	.95	1.06
Isoleucine	.65	.83	1.00	.81	.91
Phenylalanine	.80	.92	1.08	.82	.81
Tyrosine	.56	.67	.81	.57	.56
Leucine	1.55	1.98	2.46	1.59	1.57
Arginine	.87	.96	1.11	.92	.89
Histidine	.48	.55	.63	.49	.48
Glycine	.76	.83	.91	.77	.76
Glutamic acid	2.46	3.01	3.60	2.56	2.50
Serine	.66	.79	.93	.70	.69
Aspartic Acid	1.52	1.91	2.37	1.62	1.56
Taurine	.12	.12	.12	.13	.12
Proline	.91	1.08	1.25	.94	.92
Hydroxyproline	.07	.07	.07	.07	.07
Ornithine	.02	.02	.02	.02	.02
Alanine	.97	1.15	1.35	.99	.99

[a] Amino acid values are based on a percentage of diet. Samples were analyzed by Experiment Station Chemical Laboratories, University of Missouri-Columbia.

LITERATURE CITED

Chung, T.K. and D.H. Baker. 1992. Ideal amino acid pattern for 10-kilogram pigs. J. Anim. Sci. 70:3102.

Corley, J.R. and R.A. Easter. 1980. Amino acid supplementation of low-protein diets for starter pigs. J. Anim. Sci. 51:191(Suppl. 1).

Kephart, K.B. and G.W. Sherritt. 1990. Performance and nutrient balance in growing swine fed low-protein diets supplemented with amino acids and potassium. J. Anim. Sci. 68:1999.

Lepine, A.J., D.C. Mahan and Y.K. Chung. 1991. Growth performance of weanling pigs fed corn-soybean meal diets with or without whey at various L-lysine-HCl levels. J. Anim. Sci. 69:2026.

Lin, F.D., D.A. Knabe, and T.D. Tanksley, Jr. 1987. Apparent digestibilities of amino acids, gross energy and starch in corn, sorghum, wheat, barley, oat groats, and wheat middlings for growing pigs. J. Anim. Sci. 64:1655.

Owen, K.Q., J.L. Nelssen, R.D. Goodband, M.D. Tokach, B.T. Richert, K.G. Friesen, J.W. Smith, II, J.R. Bergstrom, and S.S. Dritz. 1994. Dietary lysine requirements of segregated early-weaned pigs. Kansas State University Swine Day. pp. 37-41.

Sohn, K.S., C.V. Maxwell, D.S. Buchanan, and L.L. Southern. 1994. Improved soybean protein sources for early-weaned pigs: I. Effects on performance and total tract amino acid digestibility. J. Anim. Sci. 72:622.

Southern, L.L. 1991. Digestible amino acids and digestible amino acid requirements for swine. Biokyowa Technical Review-2.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics. pp. 197-201. McGraw-Hill, Inc., New York.

Walker, W.R., C.V. Maxwell, F.N. Owens, and D.S. Buchanan. 1986. Milk verses soybean protein sources for pigs: II. Effects on amino acid availability. J. Anim. Sci. 63:513.

CHAPTER V

GLUTAMIC ACID SUPPLEMENTATION OF LOW CRUDE PROTEIN NURSERY PIG DIETS SUPPLEMENTED WITH SYNTHETIC AMINO ACIDS

M.E. Davis, B. Z. de Rodas, C. V. Maxwell, E. Broekman, and J. Chung

Department of Animal Science, Oklahoma State University, Stillwater

ABSTRACT

Forty-eight pigs were fed one of four dietary treatments to compare diets fed at Oklahoma State University containing synthetic amino acids with similar diets fed at Kansas State University. All diets were formulated to contain 1.60% lysine obtained by using either whey protein concentrate (WPC) or an amino acid mixture. Glutamic acid was added to diets as needed to adjust the essential amino acid:crude protein ratio to .50, or the essential:non-essential amino acid ratio to 1.00. Treatments 1 and 2 were diets fed in the previous experiment. The first treatment used WPC as the lysine source while the second substituted synthetic amino acids for WPC in Treatment 1. Treatments 3 and 4 were similar diets containing wheat gluten in addition to similar ingredients fed in the previous experiment. Treatment 3 modified from the original (Treatment 4) by substituting WPC for synthetic amino acids to achieve the desired lysine level. Protein sources in Treatments 1 and 2 included 20% dried whey, 6.6% select menhaden fish meal, 3.5% spray-dried plasma protein, 1.5% spray-dried blood meal, and 2.7% soy protein concentrate. Treatments 3 and 4 were formulated with similar protein ingredients except they contained 6.6% spray-dried plasma protein, 1.6% spray-dried blood meal, and an additional protein ingredient, wheat gluten at 5%. Treatment diets were fed from d 0 to 14 (Phase 1) of the experiment, after which common Phase 2 (d 14 to 28) and Phase 3 (d 28 to 42) diets were fed to all pigs to monitor any carryover effects from the treatment diets fed during Phase 1. Pigs and

feed refusals were weighed once every week and average daily gain (ADG), average daily feed intake (ADFI), and gain:feed (G/F) were assessed weekly. Blood samples were obtained via vena cava puncture on d 14 for determination of blood urea nitrogen (BUN) concentration. From d 0 to 7, ADG and ADFI were higher ($P < .05$) for pigs fed diets formulated with WPC (Treatments 1 and 3) than for those fed synthetic amino acid diets (Treatments 2 and 4). Gain:feed was higher ($P < .10$) for pigs fed Treatment 1 than for those fed the synthetic amino acid diets (Treatments 2 and 4). From d 7 to 14, pigs fed the diets containing synthetic amino acids (Treatments 2 and 4) had lower ($P < .05$) ADG than pigs fed diets formulated with WPC (Treatments 1 and 3). Pigs fed Treatments 1 and 3 had higher ($P < .10$) ADG than those fed Treatments 2 and 4 during Phase 1 (d 0 to 14). Average daily feed intake was lower ($P < .05$) for pigs fed synthetic amino acid diets (Treatments 2 and 4) than for those fed WPC diets (Treatments 1 and 3). During Phase 2, ADG was higher ($P < .05$) for pigs fed Treatment 3 than for those fed Treatment 2 and 4. Pigs fed Treatment 2 had lower ADG than those fed Treatments 1 and 3. Gain:feed improved ($P < ..05$) in pigs fed the amino acid-supplemented diets (Treatments 2 and 4) compared to those fed Treatment 1. There was no significant difference in ADG, ADFI, and G/F among treatments during Phase 3 of the experiment. Blood urea nitrogen values were highest for Treatments 1 and 3. Pigs fed Treatment 3 had higher ($P < .05$) BUN values than all other treatments, while those fed Treatment 2 had the lowest ($P < .05$) BUN concentrations. Blood urea nitrogen values did not differ between Treatments 1 and 4, though there was a tendency for BUN values for Treatment 1 to be higher ($P < .10$). These data indicate that amino acid supplementation, even with glutamic acid and separate methionine and cystine addition does not result in equal performance when compared to natural protein sources.

INTRODUCTION

The previous experiment conducted to determine the potential for the use of synthetic amino acids in the diets of Phase 1 nursery pigs resulted in poor ADG and feed efficiency when crystalline amino acids were used to achieve the same dietary lysine level as diets formulated to contain WPC as the amino acid source. This is contrary to reports obtained from a similar study conducted at Kansas State University (Owen et al., 1994), which observed acceptable performance using different natural proteins in diets with synthetic amino acid additions.

Two studies with the growing chick (Stucki and Harper, 1961 and Allan and Baker, 1974) found that excess essential amino acids were inefficient in providing amino nitrogen for the synthesis of non-essential amino acids. One possible explanation for the poor performance obtained in the previous study is that the diets containing large amounts of crystalline amino acids did not provide sufficient quantities of dispensable amino acids to meet the pigs' requirements for amino nitrogen.

In an experiment to determine the optimum dietary amino acid pattern for pigs, Wang and Fuller (1989) found nitrogen retention to be greatest when the ratio of essential:non-essential amino acids was 50:50 or 57:43. A broken line model was fitted to these values and the optimum ratio was extrapolated to be 45:55. This is close to an essential:non-essential amino acid ratio of 1.00, or an essential:crude protein ratio of 0.50. The diets formulated in the previous study containing synthetic amino acids were slightly higher than the suggested ratio, while the diets formulated at Kansas State University were closer to this finding.

This study was conducted to compare the performance of pigs fed amino acid-supplemented diets in the previous experiment with similar diets containing wheat gluten. Therefore, the specific objectives of this experiment were to: 1) compare the performance of weaned pigs fed amino acid supplemented diets formulated in the previous study with those formulated with the natural basal proteins used at Kansas State University; 2) determine if adjusting the ratio of essential amino acid:crude protein to 0.50 Phase 1 nursery pigs improves the utilization of diets containing large amounts of crystalline amino acids ; and 3) assess if separate addition of the sulfur-containing amino acids (methionine and cystine) results in improved pig performance compared to addition of only methionine.

MATERIALS AND METHODS

A total of 48 pigs averaging 21 d of age and 6.3 kg BW were blocked by weight (3 groups of 16 pigs each in each block) and stratified by litter, sex, and genotype into 12 pens with 4 pigs/pen. Pens within each block were randomly assigned one of four dietary treatments (three pens/treatment).

The four dietary treatments (Table 5.1) fed in this study were formulated to contain lysine levels at 1.65% (Table 5.2). Treatment 1 was a diet fed in the previous experiment using WPC to achieve the desired lysine level. In Treatment 2, WPC was removed and crystalline amino acids were added to achieve the same lysine level as Treatment 1 , as well as supply all other amino acids according to the ideal protein amino acid ratios suggested by Chung and Baker (1992). Treatment 3 was a diet containing wheat gluten, a higher level of plasma protein, and synthetic amino acids removed and replaced with WPC to supply the desired lysine level. Treatment 4 was a diet containing wheat gluten and synthetic amino acids. The amino acid composition of wheat gluten used to formulate Treatments 3 and 4 were obtained from Richert et al (1994). Glutamic acid was added to each diet as needed to adjust the essential amino acid:crude protein ratio to 0.50, or the essential:non-essential amino acid ratio to 1.00. Table 5.3 shows both ratios before and after glutamic acid addition. Methionine and cystine were added separately to meet their ideal protein ratios according to Chung and Baker (1991).

Phase 1 treatment diets were fed for the first 14 d of the experiment. Upon completion of Phase 1 feeding, all pigs were fed a common Phase 2 diet for 14 days, followed by a common Phase 3 diet for an additional 14 days to monitor any carryover effects from the treatment diets fed during Phase 1. A feed sample from each diet was collected for crude protein and amino acid analysis. Analysis was performed at Experiment Station Chemical Laboratories (University of Missouri-Columbia).

Pig body weight and feed intake were recorded weekly and ADG, ADFI, and G/F were calculated. Blood samples were obtained via vena cava puncture on d 14 and serum was analyzed for blood urea nitrogen concentration using Roche® reagents (Roche Diagnostic Systems, Sommerville, NJ).

Pigs were housed in an environmentally controlled nursery with elevated pens (1.14m x 1.5m) and woven wire flooring. Access to feed and a nipple waterer were available ad libitum. Temperature was maintained initially at 30°C and was decreased by 1°C weekly.

Data were analyzed as a randomized complete block design (Steel and Torrie, 1980) with pen as the experimental unit and blocks based on initial BW. Analysis of variance was performed using the GLM procedures of SAS (1988). The statistical model included block, treatment, and week, as well as block*treatment and week*treatment interactions. Specific differences between treatment means were determined by *t*-test when treatment was significant.

RESULTS

Tables 5.4 and 5.5 show the results of pigs fed the four treatment diets during Phase 1 and the results of the amino acid analysis of each diet. During the first week of the experiment (d 0 to 7) ADG was lower ($P < .05$) for pigs fed the diets containing synthetic amino acids (Treatments 2 and 4) than for those fed the WPC diets (Treatments 1 and 3). Average daily feed intake was higher ($P < .05$) for those pigs fed the WPC diets than for those fed diets supplemented with synthetic amino acids(Treatments 1 and 3 vs. Treatments 2 and 4). Gain:feed tended to be greater ($P < .10$) for pigs fed the WPC diet from the previous experiment (Treatment 1) than for those fed the synthetic amino acid diet (Treatment 2).

Average daily gain during the second week (d 7 to 14) of the experiment was higher ($P < .05$) for pigs fed diets containing WPC (Treatments 1 and 3) than for those fed the synthetic amino acid diet fed in the previous experiment (Treatment 2). Pigs fed the WPC diet containing wheat gluten (Treatment 3) had a higher ($P < .05$) ADG than those fed the synthetic amino acid diet fed in the previous experiment (Treatment 2), but a lower ($P < .05$) ADG than those fed the WPC diet from the previous experiment (Treatment 1).

Pigs fed the synthetic amino acid diets (Treatments 2 and 4) during Phase 1 (d 0 to 14) tended to have lower (P < .10) ADG than those fed the diets formulated with WPC (Treatments 1 and 3). Pigs fed the WPC diet from the previous experiment (Treatment 1) tended to have higher (P < .10) ADG than those fed the WPC diet containing wheat gluten (Treatment 3). Average daily feed intake was depressed (P < .05) in pigs fed diets formulated with synthetic amino acids (Treatments 2 and 4) compared to pigs fed the WPC diets (Treatments 1 and 3).

Carryover effects from the treatment diets fed during Phase 1 were observed when a common Phase 2 diet was fed. Gain:feed was higher (P < .05) in pigs fed diets supplemented with synthetic amino acids (Treatments 2 and 4) during Phase 1 than in pigs previously fed the WPC diet from the previous study (Treatment 1). Pigs previously fed the synthetic amino acid diet had higher (P < .05) G/F than pigs previously fed diets containing WPC.

For the overall trial period (d 0 to 42) ADG and ADFI tended to be higher (P < .10) in pigs fed the WPC diet containing wheat gluten (Treatment 3) than in those fed diets containing synthetic amino acids (Treatment 2 and 4). Additionally, ADG and ADFI tended to be lower (P < .10) for pigs fed the synthetic amino acid diet from the previous experiment (Treatment 2) than for those fed diets formulated with WPC (Treatments 1 and 3).

Blood urea nitrogen values of pigs fed the synthetic amino acid diet from the previous experiment had lower (P < .05) BUN concentrations than those fed the other treatments, while pigs offered the WPC diet containing wheat gluten had higher BUN values (P < .05) than pigs fed the other dietary treatments. Pigs fed the WPC diet from the previous experiment and those fed the synthetic amino acid diet containing wheat gluten had similar BUN concentrations of 6.57 and 4.69 mg/dl, respectively (P > .10).

DISCUSSION

Diets fed in the previous study were compared to similar diets (but with a different natural protein source) fed at Kansas State University because of the improvement observed in pig performance when lysine was increased in the Kansas State University study using high levels of synthetic amino acids (Owen et al., 1994). Diets formulated with a high synthetic amino acid content and fed in the previous trial did not result in satisfactory performance when compared to a positive control diet formulated with WPC as the amino acid source. It was our speculation that the positive results when feeding synthetic amino acid diets to young pigs in the Kansas State University study were obtained because all diets contained high levels of synthetic amino acids and were not compared to a natural protein positive control diet.

In the present study, diets formulated with synthetic amino acids failed to result in satisfactory pig performance when compared to the basal diets formulated with WPC. This was evident regardless of whether the original diets used ingredients in diets formulated in the previous study or in the Kansas State University study. As theorized, the synthetic amino acid diet fed in a previous study at Kansas State University did not result in pig performance comparable to a diet formulated with a natural protein source.

Supplementing diets with glutamic acid to achieve an essential:non-essential amino acid ratio of 1.00 did not improve the performance of pigs fed the synthetic amino acid diet formulated in the previous experiment when compared to the natural protein control diet containing WPC. Mitchell, Jr. et al. (1968) conducted an experiment to determine at what level glutamic acid addition to a semi-synthetic diet would result in the greatest nitrogen retention after a previous experiment using glutamic acid supplementation to make diets isonitrogenous showed evidence of an amino acid imbalance. Glutamic acid addition in the present experiment should not have resulted in an amino acid imbalance since it was added to provide a 1:1 ratio of essential:non-essential amino nitrogen. This ratio was consistent with the findings of Mitchell, Jr. et al. (1968) that resulted in the greatest nitrogen retention. They did not assess pig growth or feed efficiency so it is unclear whether this ratio would support acceptable gain in pigs fed diets with synthetic amino acid additions.

An experiment conducted by Roth et al. (1994) found that several of the amino acids considered non-essential in pig diets may not be completely dispensable. They discovered that though alanine, aspartic acid, glycine, and serine are completely dispensable in the growing pig, arginine, glutamic acid, and proline must be provided in the diet. Although glutamic acid was provided in the diets in the present study and diets were formulated to meet or exceed the ideal protein ratio according to Chung and Baker (1991), it is possible that crude protein levels were lowered enough in the diets formulated with synthetic amino acids to limit proline.

Fickler et al. (1994) fed a chemically defined amino acid diet to 10 to 15 kg pigs and compared growth and nitrogen retention to a commonly fed diet containing grain, SBM, fish meal, and skim milk powder. The amino acid diet was formulated to contain ideal ratios of essential amino acids and a mixture of non-essential amino acids including alanine, aspartic acid, glutamic acid, glycine, proline, and serine, instead of supplementing only with glutamic acid as in the present experiment. Growth rate and nitrogen retention decreased and percentage of nitrogen utilized increased in pigs fed the amino acid diet as compared to the control diet in the Fickler study. Their suggestion of raising the amount of dispensable amino acids and improving the pattern of indispensable amino acids could be applicable to the present study, since addition of glutamic acid singly did not produce satisfactory pig performance.

Blood urea nitrogen concentrations observed in this experiment were varied, particularly between Treatments 2 and 3. Blood urea nitrogen concentration was used as an indicator of amino acid utilization. When an amino acid is limiting or at deficient levels, it restricts the use of other amino acids for protein synthesis. These surplus amino acids are used for urea synthesis thereby increasing BUN concentrations. Supplementing a deficient diet with the respective limiting amino acid has been shown to decrease plasma urea nitrogen concentrations (Coma et al., 1995). The high BUN concentrations observed in pigs fed Treatment 3 suggest a diet containing excesses of amino acids relative to the one most limiting. The extremely low BUN concentrations and performance of pigs fed Treatment 2 indicate a diet extremely low or deficient in protein, or some amino acid. Blood urea nitrogen values and performance was similar for pigs fed Treatments 1 and 4, which indicates the Kansas State University amino acid diet resulted in similar amino acid utilization as Oklahoma State University's positive control diet,

IMPLICATIONS

Diets formulated to contain synthetic amino acids did not result in satisfactory pig performance when compared to diets formulated with a natural protein source (in this case, WPC). The original Kansas State University synthetic amino acid diet resulted in poorer pig performance than a natural protein positive control diet, and was no better than the synthetic amino acid diet formulated in the previous experiment. Glutamic acid addition to keep diets isonitrogenous did not result in improved performance when pigs were fed synthetic amino acid diets compared to diets formulated with WPC.

Table 5.1. Composition of experimental diets comparing performance of pigs fed diets from the previous experiment using whey protein concentrate and synthetic amino acids with similar diets containing wheat gluten.

	Treatments			
Ingredients	1	2	3	4
Corn	34.31	32.15	33.00	37.67
Soy protein concentrate	2.67	2.67	-	-
SBM, 46.5% CP	-	-	.20	.20
Lactose	3.29	4.65	10.00	10.00
Whey	20.00	20.00	20.00	20.00
St. Rolled Oats	10.00	10.00	-	-
AP-301	1.50	1.50	1.60	1.60
AP-920	3.50	3.50	6.63	6.63
Whey protein concentrate, 77% CP	9.60	-	10.26	-
Fish meal	6.57	6.57	5.00	5.00
Wheat Gluten	-	-	5.00	5.00
Glutamic Acid	1.22	3.35	-	1.56
Lysine	-	.55	-	.59
Methionine	.06	.22	.03	.12
Cystine	-	.17	-	.11
Threonine	-	.29	-	.20
Isoleucine	-	.30	-	.27
Valine	-	.12	-	-
Tryptophan	-	.10	-	.05
Zinc Oxide	.30	.30	.38	.38
Dicalcium Phosphate.	1.20	1.39	1.50	1.70
Soy Oil	4.00	4.00	5.00	5.00
Neoterramycin[a]	1.00	1.00	1.00	1.00
Ethoxiquin	.03	.03	-	-
Flavor	.10	.10	-	-
Vit TM Premix[b]	.38	.38	.40	.40
$CuSO_4$	.07	.07	-	-
Cornstarch	-	3.20	-	2.52
Sucrose	-	3.19	-	-
Salt	.20	.20	-	-

[a] Contained 10 g of Neomycin and 5 g of oxytetracycline per lb. of product.

[b] 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 kilogram 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 D_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, 150 mg of Fe, 15 mg of Zn, and .37 mg of I per kilogram of feed during Phase 2.

Table 5.2. Calculated compositions of crude protein, lactose, amino acids, calcium, and phosphorus comparing dietary protein supplementation with whey protein concentrate or synthetic amino acids.

	Treatments			
Calculated Composition	1	2	3	4
Crude Protein, total	25.53	21.64	26.88	21.81
Lactose	18.00	18.00	24.74	23.30
Calcium	.92	.91	.91	.91
Phosphorus	.80	.80	.83	.83
Lysine	1.64	1.62	1.65	1.65
Tryptophan	.35	.29	.41	.29
Threonine	1.20	1.09	1.31	1.11
Methionine	.49	.49	.50	..48
Cystine	.51	.49	.50	.43
Valine	1.38	1.11	1.46	1.07
Isoleucine	1.05	.96	1.07	.97
Phenylalanine	1.00	.85	1.10	.97
Tyrosine	.94	.79	.73	.59
Leucine	2.36	1.67	2.49	1.83
Arginine	1.12	.96	1.05	.90
Histidine	.70	.53	.74	.57

Table 5.3. Essential amino acid : crude protein (EAA:CP) and essential : non-essential amino acid (EAA:NEAA) ratios before addition of glutamic acid (1) and after addition of glutamic acid (2).

	1		2	
Trt	EAA:CP	EAA:NEAA	EAA:CP	EAA:NEAA
1	.525	1.11	.502	1.00
2	.590	1.44	.503	1.03
3	.488	.95	.483	.93
4	.539	1.17	.498	.99

Table 5.4. Results of pigs fed synthetic amino acid diets (2 and 4) verses those fed natural protein diets (1 and 3) during Phase 1[1].

	Treatment			
	1	2	3	4
d 0 to 7				
ADG, g	329.40^{b}	184.14^{c}	305.64^{b}	192.78^{c}
ADFI, g	300.78^{b}	222.48^{c}	314.82^{b}	200.88^{c}
Gain:Feed	1.10^{e}	$.83^{f}$	$.98^{e,f}$	$.97^{e,f}$
d 7 to 14				
ADG, g	436.32^{b}	298.08^{c}	369.36^{d}	$328.32^{c,d}$
ADFI, g	534.60	406.62	478.96	397.98
Gain:Feed	.82	.75	.77	.82
d 0 to 14 (Phase 1)				
ADG, g	382.86^{e}	241.11^{f}	337.50^{g}	260.55^{f}
ADFI, g	417.69^{b}	314.55^{c}	396.90^{b}	299.43^{c}
Gain:Feed	.96	.79	.88	.89
d 14 to 28 (Phase 2)				
ADG, g	582.66	548.10	611.55	573.75
ADFI, g	843.75	736.83	864.54	786.78
Gain:Feed	$.70^{b}$	$.75^{c}$	$.72^{b,d}$	$.74^{c,d}$
d 28 to 42 (Phase 3)				
ADG, g	589.95	596.97	674.46	594.54
ADFI, g	1150.20	1082.70	1217.16	1143.18
Gain:Feed	.52	.56	.56	.52
d 0 to 42				
ADG, g	518.49^{df}	462.06^{e}	541.17^{d}	476.28^{ef}
ADFI, g	803.88^{df}	711.36^{e}	826.20^{d}	743.13^{ef}
Gain:Feed	.72	.70	.72	.72
BUN (mg/dl)	6.57^{a}	1.75^{b}	11.35^{c}	4.69^{a}

[1] LS means of 3 pens/treatment with 4 pigs/pen.
[a,b,c] Values lacking a common superscript letter differ ($P<.05$).
[d,e,f] Values lacking a common superscript letter differ ($P<.10$).

Table 5.4. Results of pigs fed synthetic amino acid diets (2 and 4) verses those fed natural protein diets (1 and 3) during Phase 1[1].

	Treatment			
	1	2	3	4
d 0 to 7				
ADG, g	329.40^{b}	184.14^{c}	305.64^{b}	192.78^{c}
ADFI, g	300.78^{b}	222.48^{c}	314.82^{b}	200.88^{c}
Gain:Feed	1.10^{e}	$.83^{f}$	$.98^{e,f}$	$.97^{e,f}$
d 7 to 14				
ADG, g	436.32^{b}	298.08^{c}	369.36^{d}	$328.32^{c,d}$
ADFI, g	534.60	406.62	478.96	397.98
Gain:Feed	.82	.75	.77	.82
d 0 to 14 (Phase 1)				
ADG, g	382.86^{e}	241.11^{f}	337.50^{g}	260.55^{f}
ADFI, g	417.69^{b}	314.55^{c}	396.90^{b}	299.43^{c}
Gain:Feed	.96	.79	.88	.89
d 14 to 28 (Phase 2)				
ADG, g	582.66	548.10	611.55	573.75
ADFI, g	843.75	736.83	864.54	786.78
Gain:Feed	$.70^{b}$	$.75^{c}$	$.72^{b,d}$	$.74^{c,d}$
d 28 to 42 (Phase 3)				
ADG, g	589.95	596.97	674.46	594.54
ADFI, g	1150.20	1082.70	1217.16	1143.18
Gain:Feed	.52	.56	.56	.52
d 0 to 42				
ADG, g	518.49^{df}	462.06^{e}	541.17^{d}	476.28^{ef}
ADFI, g	803.88^{df}	711.36^{e}	826.20^{d}	743.13^{ef}
Gain:Feed	.72	.70	.72	.72
BUN (mg/dl)	6.57^{a}	1.75^{b}	11.35^{c}	4.69^{a}

[1] LS means of 3 pens/treatment with 4 pigs/pen.

[a,b,c] Values lacking a common superscript letter differ (P<.05).

[d,e,f] Values lacking a common superscript letter differ (P<.10).

Table 5.5. Amino acid analysis of experimental diets fed during Phase 1.[a]

Amino acids	Treatments 1	2	3	4
Crude protein	23.18	18.49	24.71	21.56
Lysine	1.51	1.27	1.50	1.34
Tryptophan	.33	.28	.36	.28
Threonine	1.16	.92	1.24	1.00
Methionine	.48	.45	.46	.41
Cysteine	.48	.44	.58	.50
Valine	1.28	.95	1.38	1.08
Isoleucine	.98	.77	1.03	.88
Phenylalanine	.97	.72	1.10	.95
Tyrosine	.66	.47	.75	.62
Leucine	2.18	1.34	2.34	1.82
Arginine	.99	.80	.98	.87
Histidine	.58	.43	.64	.55
Glycine	.88	.75	.90	.82
Glutamic acid	4.25	4.59	4.20	4.22
Serine	.94	.63	1.06	.84
Aspartic acid	2.15	1.35	2.12	1.57
Taurine	.00	.15	.13	.14
Proline	1.30	.85	1.69	1.40
Hydroxyproline	.07	.07	.06	.06
Ornithine	.01	.01	.01	.01
Alanine	1.30	.90	1.33	1.08
Hydroxylysine	.01	.01	.01	.01

[a] Amino acid values are based on a percentage of diet. Samples were analyzed by Experiment Station Chemical Laboratories, University of Missouri-Columbia.

LITERATURE CITED

Allen, N.K. and D.H. Baker. 1974. Quantitative evaluation of nonspecific nitrogen sources for the growing chick. Poult. Sci. 53:258.

Chung, T.K. and D.H. Baker. 1992. Ideal amino acid pattern for 10-kilogram pigs. J. Anim. Sci. 70:3102.

Coma, J., D. Carrion, and D.R. Zimmerman. 1995. Use of plasma urea nitrogen as a rapid response criteria to determine the lysine requirement of pigs. J. Anim. Sci. 73:472.

Fickler, J., F.X. Roth and M. Kirchgessner. 1994. Use of a chemically defined amino acid diet in a N-balance experiment with piglets 1. Communication on the importance of non-essential amino acids for protein retention. J. Anim. Physiol. and Anim. Nutr. 72:207.

Mitchell, Jr., J.R., D.E. Becker, A.H. Jensen, H.W. Norton, and B.G. Harmon. 1965. Lysine need of swine at two stages of development. J. Anim. Sci. 24:409.

Owen, K.Q., J.L. Nelssen, R.D. Goodband, M.D. Tokach, B.T. Richert, K.G. Friesen, J.W. Smith, II, J.R. Bergstrom, and S.S. Dritz. 1994. Dietary lysine requirements of segregated early-weaned pigs. Kansas State University Swine Day. pp. 37-41.

Richert, B. T., J. D. Hancock, and J.L. Morrill. 1994. Effects of replacing milk and soybean products with wheat glutens on digestibility of nutrients and growth performance in nursery pigs. J. Anim. Sci. 72:151-159.

Roth, Von F.X, J. Fickler and M. Kirchgessner. 1994. N-balance of piglets as related to the omission of individual non-essential amino acids from the diet. 2. Communication on the importance of non-essential amino acids for protein retention. J. Anim. Physiol. a. Anim. Nutr. 72:215.

SAS. 1985. SAS User's Guide: Statistics. SAS Inst., Inc., Cary, NC.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and Procedures of Statistics. pp. 197-201. McGraw-Hill, Inc., New York.

Stucki, W.P. and A.E. Harper. 1961. Importance of dispensable amino acids for normal growth of chicks. J. Nutr. 62:77.

Wang, T.C. and M.F. Fuller. 1989. The optimum dietary amino acid pattern for growing pigs. Br. J. of Nutr. 62:77.

VITA

Mari Ellen Davis

Candidate for the Degree of

Master of Science

Thesis: DETERMINATION OF THE LYSINE REQUIREMENT AND POTENTIAL FOR SYNTHETIC AMINO ACID USE IN THE DIETS OF 5 TO 15 KG PIGS

Major Field: Animal Science

Biographical:

Personal Data: Born in Scotland Neck, North Carolina, on November 10, 1971, the daughter of Kenneth and Linda Davis.

Education: Received high school diploma from St. Mary's College, Raleigh, North Carolina in May, 1990; received Bachelor of Science degree in Animal Science from North Carolina State University, Raleigh, North Carolina in May of 1994. Completed the requirements for the Master of Science degree in Animal Science at Oklahoma State University, Stillwater, Oklahoma in December of 1996.

Experience: Employed by the Swine Research Unit at North Carolina State University, Raleigh, North Carolina during my undergraduate work from 1990-1994. Employed by Dr. Joan Eisemann to assist with data collection in 1992 at North Carolina State University, Raleigh, North Carolina. Summer internship with Brown's of Carolina, Warsaw, North Carolina in 1994.

Professional Memberships: American Society of Animal Science.