ESTIMATION OF THE LYSINE REQUIREMENT OF WEANLING PIGS AND THE POTENTIAL FOR CRYSTALLINE AMINO ACID SUBSTITUTIONS FOR NATURAL AMINO ACID SOURCES

By

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FORMAT OF THESIS

This thesis 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 the degree of Doctor of Philosophy. Each paper is complete in itself containing an abstract, introduction, materials and methods, results, discussion, implication, and literature cited section.

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CHAPTER I

INTRODUCTION

In modern swine production systems, early weaning has become a common practice because it reduces the reproduction cycle of the sow herd and it allows sows to return production as soon as possible in order to produce more pigs per year. Recent trends in the swine industry have been toward earlier weaning with many systems routinely weaning pigs as early as 19 to 21 days of age in a traditional production system and as early as 10 to 15 days of age in a segregated early weaning system. The practice of segregated early weaning, in which pigs are transferred and raised in an off-site nursery separate from the sow herd, attempts to avert and minimize the vertical transmission of various infectious diseases by segregating pigs at weaning (Dritz et al., 1994). Recently, segregated early weaning has become a common practice in the commercial swine industry to improve the efficiency of swine production.

The establishment of reliable lysine requirement data for the weanling pig is economically important to the swine industry because lysine is the first limiting amino acid in typical corn-soybean meal based diets (Rusell et al., 1983; Lepine et al., 1991; Owen et al., 1995; Libal et al., 1997; Mavromichalis et al., 1998). Feed formulation for the diets of pigs often is based on the desirable ratios of indispensable amino acids to lysine. However, estimations of the lysine requirement of segregated early-weaned pigs have been limited. Several experiments (Stahly et al., 1994; Owen et al., 1994) with

segregated early-weaned pigs suggested that the lysine requirement is much higher than that recommended by NRC (1988). In addition, lysine concentrations in diets typically used in the swine industry are much higher than previously recommended.

Most swine diets consisting of grain-soybean meal based mixtures tend to contain excesses of many dispensable and indispensable amino acids except the first limiting amino acid, lysine. These excess dispensable and indispensable amino acids in swine diets have been suggested to reduce animal performance resulting inefficient and uneconomical production (Kerr, 1988). In addition, an oversupply of these dispensable and indispensable amino acids can lead to excess nitrogen excretion. Excess amino acids are catabolized and excreted as urinary nitrogen in the form of urea that can cause pollution to the environment.

The supplementation of crystalline amino acids to low-protein swine diets can be used to overcome potential deficiencies of amino acids in the diet (Tuitoek et al., 1997) and to improve the amino acid balance in the diet to optimize swine performance. In swine production, the reduction of nitrogen excretion is related to the protein content and amino acid balance of the diet, because an oversupply of protein and an imbalance of amino acids are mainly excreted in the urine (Valaja et al., 1993). Thus, the addition of optimal crystalline (synthetic) amino acids to low-protein diets is one way to decrease nitrogen excretion per unit of pork produced (Lenis, 1989).

The specific objectives of this study were: (1) to determine the lysine requirement of segregated early-weaned pigs fed a high nutrient dense diet using whey protein concentrate as the source of amino acids during the first two weeks post weaning, (2) to determine the efficacy of whey protein concentrate and a mixture of crystalline amino

acids at two lysine levels on the performance and plasma urea nitrogen of segregated early-weaned pigs, (3) to evaluate the efficacy of replacing whey protein concentrate with crystalline amino acids in weanling pig diets on growth performance and plasma urea nitrogen, and (4) to estimate if the specific additions of essential and non-essential amino acids to an ideal blend of amino acids in a low protein diet could improve growth performance of weanling pigs.

CHAPTER II

REVIEW OF LITERATURE

Essential and Nonessential Amino Acids for Swine

Essential and Nonessential Amino Acids

In most practical swine diets, proteins that are thought to be essential dietary constituents are composed of amino acids, and these amino acids are the actual essential nutrients. There are twenty different amino acids commonly found in proteins. However, not all of these amino acids are essential dietary components (Lewis, 1991; NRC, 1998); because pigs can synthesize some amino acids by using carbon skeletons and amino groups derived from other amino acids present in excess of the requirement (NRC, 1998). Thus, these amino acids are not required in the diet. Amino acids synthesized in this manner are termed nonessential (or dispensable) amino acids. On the other hand, amino acids that cannot be synthesized by pigs, or they cannot be synthesized at a rate sufficient to permit optimal growth or reproduction (NRC, 1998), are termed essential (or indispensable) amino acids. Therefore, the essential amino acids must be supplied in the diet for optimal growth of swine.

In 1940s and 1950s, many studies were conducted to determine which amino acids are essential and which are nonessential by researchers at Cornell and Purdue

Universities. Based on the results of these studies, Lewis (1991) provided information on the essential and nonessential classification of amino acids (Table 2.1).

Table 2.1. Amino acids classification for swine[a].

Amino Acid	
Essential	Nonessential
Arginine	Alanine
Histidine	Asparagine
Isoleucine	Aspartic acid
Leucine	Cysteine
Lysine	Glutamic acid
Methionine	Glutamine
Phenylalanine	Glycine
Threonine	Proline
Tryptophan	Serine
Valine	Tyrosine

[a] Lewis, 1991.

Amino Acids that Can Be Conditionally Essential or Nonessential in Certain Situations

Arginine

Among the amino acids classified into essential and nonessential categories, some amino acids are not pertinent to the classification in certain situations. In general, arginine is considered an essential amino acid for swine. However, Wu and Knabe (1995) found that arginine can be synthesized from glutamine in enterocytes of neonatal pigs. In this study, the authors demonstrated that the intestinal synthesis of arginine has physiological and nutritional importance to maintain arginine homeostasis and to support the pig's rapid growth during the newborn period when sow's colostrum and milk are deficient in arginine. However, some reports indicated that young pigs require a dietary source of arginine to achieve maximal growth performance during the early stage of the

growth period (Mertz et al., 1952; Southern and Baker, 1983). Based on these results, NRC (1998) suggested that diets of growing pigs must contain a source of arginine because the amount of arginine synthesis from glutamine in enterocytes of neonatal pigs is probably not enough to meet nutrient requirements during the early stage of growth.

Sows, on the other hand, can synthesize arginine in sufficient amounts to meet their needs during the postpubertal growth and pregnancy period (Easter et al., 1974; Easter and Baker, 1976). In contrast, sows probably cannot synthesize arginine at a rate sufficient to meet most or all of their requirements during the lactation period (NRC, 1998). Moreover, arginine does not seem to be a dietary requirement for maintenance of adult nongravid gilts (Baker et al., 1966).

Cysteine and Methionine

Among the twenty different amino acids that are commonly found in proteins, two sulfur-containing amino acids are cysteine and methionine. Cysteine can be formed endogenously from methionine via the trans-sulfuration pathway but not vice versa (Roth and Kirchgessner, 1989). Thus, whereas methionine is considered an essential amino acid, cysteine is classified as a nonessential amino acid only if methionine is included in the diet at adequate levels to supply the total sulfur amino acid requirement (Chung and Baker, 1992b). If cyst(e)ine is not present in swine diets, methionine can meet the total requirement for sulfur amino acids (NRC, 1998). On the other hand, cysteine is easily oxidized to form covalently linked dimeric amino acid called cystine that is linking two cysteine molecules by means of a disulfide bridge (Lehninger et al., 1993). The reaction

between cysteine and cystine is freely reversible such that both compounds are equal in rendering cysteine bioactivity for support of protein synthesis (Baker, 1994).

There have been many studies to estimate the maximal portion of the total sulfur amino acid requirement that can be provided by cystine for growing pigs; however, the results of these studies are not in agreement and the cystine replacement values of the total sulfur amino acid requirement range between 40 and 70% (Shelton et al., 1951; Curtin et al., 1952; Becker et al., 1955; Mitchell, Jr. et al, 1968; Baker et al., 1969b; Roth and Kirchgessner, 1987, 1989). In 1992, Chung and Baker, who studied the maximal proportion of the young pig's sulfur amino acid requirement that can be furnished by cystine, proposed the possible reasons why there were disagreement in those published results: (1) using different response criteria, (2) using many different diets with much variances in both metabolizable energy and crude protein levels, (3) varying in dietary methionine:cystine ratios, (4) using the tabulated rather than analytical values of the total sulfur amino acid, (5) underestimaton of the total sulfur amino acid in diets because of the use of analytical procedures (i.e., acid hydrolysis without performic acid peroxidation) that partially degrade methionine and cystine, and (6) not considering the total sulfur amino acid bioavailability in basal diets or feed ingredients. Furthermore, these researchers implied that no more than 50% of young pig's total sulfur amino acid requirement could be provided by cystine.

Phenylalanine and Tyrosine

Phenylalanine and tyrosine belong to aromatic amino acid groups that are relatively nonpolar (hydrophobic) and contain aromatic side chains in their chemical

structure (Lehninger et al., 1993). Phenylalanine, which is considered to be an essential amino acid, can be converted to tyrosine but not vice versa (Lewis, 1991); this irreversible reaction is catalyzed by the action of phenylalanine hydroxylase which hydroxylates phenylalnine at C-4 of the phenyl group to produce tyrosine (Lehninger et al., 1993; Baker, 1994). Thus, tyrosine is classified as a nonessential amino acid. If tyrosine is not included in swine diets, phenylalanine can meet the total requirement for tyrosine (NRC, 1998). The optimal portion of the total aromatic amino acid (i.e., phenylalanine + tyrosine) requirement that can be supplied by tyrosine is approximately 50% for growing pigs (Robbins and Baker, 1977).

Proline

Proline is generally classified as a nonessential amino acid for swine. Ball et al. (1986), however, reported that 2.5 kg neonatal pigs required 13.9 and 14.2 g of proline per kg diet when they were fed 200 and 260 g of protein per kg of a dried skim milk diet, respectively, using phenylalanine oxidation as an indicator of proline adequacy. In addition, they suggested that piglets of 2.5 kg are not able to synthesize proline rapidly enough to meet their requirements, and thus they require a dietary source of proline. In contrast, Chung and Baker (1993) observed that 5-kg weanling pigs fed a proline-free chemically-defined amino acid basal diet showed no significant responses in daily gain, feed intake, and feed efficiency to additional proline during a 28-d feeding period. Based on these results, the authors indicated that young pigs were apparently able to synthesize sufficient amounts of proline endogenously to meet their needs for both growth and

maintenance. There have been no research reports that pigs which are in the weight category of greater than 5-kg need a dietary source of proline.

Histidine

Although an amino acid is essential for growth and reproduction for pigs, it may not be nonessential for their maintenance. As an example, histidine is a dietary essential amino acid during pregnancy of swine (Easter and Baker, 1977), but this amino acid is not required in the diet for maintenance of the nongravid postestrual gilts (Baker et al., 1966).

Glutamine

Glutamine is generally classified as a nonessential amino acid. However, glutamine can be a conditionally essential amino acid in certain situations. Lacey and Wilmore (1990), who reviewed many studies on the nonessential amino acid glutamine, suggested that glutamine is probably considered to be a conditionally essential amino acid in animals and humans during critical illness because it serves as a preferred respiratory fuel for rapidly proliferating cells such as enterocytes and lympocytes. In addition, they also indicated that providing exogenous glutamine seems to sustain cell proliferation in the gastrointestinal tract, and it is also important to maintain the immune responses of the host. Recently, Wu et al. (1996) observed that in early weaned pigs fed a corn-soybean meal-based diet, dietary addition of 1.0% glutamine prevented jejunal atrophy during the first-week postweaning and increased the gain:feed ratio by 25% during the second-week postweaning. Based on these observations, these authors

concluded that dietary glutamine supplementation for young pigs probably provides an experimental basis for intestinal use of glutamine in swine production as well as in clinical nutrition to prohibit intestinal epitherial damages.

The Order of Most Limiting Amino Acids for Swine Fed Typical Corn-Soybean Meal Based Diets

For pigs, a limiting amino acid is the amino acid of a protein that shows the greatest percentage deficit in comparison to the amino acid requirements of pigs. The amino acid that is present in the least amount relative to requirement of pigs is termed the first-limiting amino acid. If the deficiency of this amino acid is fixed, then the amino acid that is next lowest in relation to the requirement of pigs is termed the second-limiting amino acid. Among essential amino acids, lysine has been considered the first limiting amino acid in typical corn-soybean meal based diets for swine (Russell et al., 1983; Lepine et al., 1991; Owen et al., 1995; Libal et al, 1997; Mavromichalis et al., 1998).

However, there has been confusion regarding other limiting amino acids and their order of limitation with the exception of lysine for young growing pigs fed low-protein, corn soybean meal based diets. Corley and Easter (1983) conducted a study to evaluate the limiting amino acids in a low protein corn-soybean meal based diet (14% CP) for starter pigs from 4 to 8 weeks of age. These researchers indicated that tryptophan is second and threonine is the third limiting amino acid in a low-protein corn-soybean meal based diet for starter pigs. However, Russell et al. (1983) observed that in growing pigs fed a lysine fortified, corn soybean meal based diet (12% CP) that tryptophan and

threonine were equally second limiting. In addition, in this study, the authors indicated that methionine may be the fourth limiting amino acid. In contrast, Russell et al. (1987), who evaluated an 11% CP corn-soybean meal diet containing crystalline lysine, tryptophan, and threonine, reported that this low-protein diet was not deficient in either methionine or total nitrogen, but was deficient in valine for 20 kg pigs. However, Mavromichalis et al. (1998) reported that lysine is the first-limiting and tryptophan, threonine, methionine, and valine are equally the second-limiting amino acids in a reduced protein (13.5% CP) corn-soybean meal-based diet with 8% whey for 10-kg pigs.

The First Limiting Amino Acid in a Typical Corn-Soybean Meal Based Diet for Swine: Lysine

In corn protein, the first limiting amino acid is tryptophan and the second limiting amino acid is lysine (Baker et al., 1969a). Because an applicable amount of tryptophan is contained in soybean meal, lysine is the first limiting amino acid in a typical corn-soybean meal based diet for swine (Russell et al., 1983; Lepine et al., 1991; Owen et al., 1995; Libal et al., 1997; Mavromichalis et al., 1998).

Lysine has an asymmetric carbon atom in its structure and, thus, it can exist in two forms (as D- or L-isomer). It is known that pigs cannot utilize D-lysine. This is because there is no transaminase capable of converting α-ketolysine to L-lysine, and thus D-lysine and the α-ketoanalogue of lysine have no biological efficacy in animals (Sugahara et al., 1967; Baker, 1986). In these days, most synthetic lysine is made via fermentative synthesis that yields lysine in the L-form, usually as L-lysine·HCl

(monohydrochloride). In general, feed grade lysine contains a minimum of 98% L-lysine·HCl which is equivalent to 78% actual lysine (Lewis, 1991).

Lysine Requirement for Swine

General

The establishment of reliable lysine requirement data for pigs is economically important to the swine industry because lysine is the first limiting amino acid in typical corn-soybean meal based diets commonly fed to pigs (Russell et al., 1983; Lepine et al., 1991; Owen et al., 1995; Libal et al., 1997; Mavromichalis et al., 1998). Also, feed formulation for the diets of pigs often is based on the desirable ratios of indispensable amino acids to lysine.

The lysine requirement of pigs can be affected by various dietary and physiological factors, such as energy density and protein concentration of the diet, the source of lysine, amino acid balance, type of feedstuff in the diet and its amino acid digestibility, and initial and final pig weights. The NRC (1998) estimates the lysine requirement of 3 to 5 kg, 5 to 10 kg and 10 to 20 kg pigs (allowed feed ad libitum, 90% dry matter) as 1.50%, 1.35% and 1.15% of the diet on a total basis, respectively.

Lysine Requirement for Segregated Early-Weaned Pigs

Segregated early weaning (SEW) implies that pigs are weaned at an earlier age than the conventional weaning age (i.e., 21 days of age), and they are transferred and raised in an off-site nursery separate from the sow herd. Weaning at an early age attempts to avert and minimize the vertical transmission of various infectious diseases by segregating pigs at weaning (Dritz et al., 1994).

Research estimating the lysine requirement of SEW pigs is limited. Stahly et al. (1994) suggested that in SEW pigs fed 5 experimental lysine concentrations (.6, .9, 1.2, 1.5 or 1.8% lysine), feed efficiency was optimized by dietary lysine concentration of 1.8% for high lean growth lines. Owen et al. (1994) reported that the diets for SEW pigs less than 5.0 kg needed to be formulated to contain at least 1.70% lysine and that the transition diet for pigs weighing from 5.0 kg to 6.8 kg should be formulated to contain approximately 1.50 to 1.60% lysine. In addition, in this study, they also suggested that SEW pigs require approximately 5.2 and 6.2 g/d of lysine from day 0 to 7 and day 0 to 14 postweaning, respectively, to optimize growth performance. A study by Williams et al. (1994), who conducted an experiment with pigs weighing from 6 to 114 kg live weight to determine the impact of a low and high level of immune system activation and dietary amino acid regimen on pig growth, indicated that pigs (6 to 27 kg BW) with low immune system activation had a greater capacity for protein deposition and a greater dietary lysine requirement (1.5% total lysine) than those with high immune system activation (1.2% total lysine). These results suggest that pigs with low immune system activation had a

greater capacity for proteinaceous tissue growth and greater dietary amino acid needs (expressed as a % or grams per day) than those with a high immune system activation.

Ideal Protein for Swine

Ideal Protein

An ideal protein for swine refers to a protein that is perfectly balanced in terms of its amino acid content and its supply of non-essential nitrogen (Cole, 1980). In 1981, the British ARC proposed an ideal protein for swine in which essential amino acids were listed as ratios to lysine (Baker, 1997). Thus, to use an ideal protein ratio for swine feed formulation, the lysine requirement should be determined using a growth assay, and then the concentrations of other essential amino acids are determined by using the ratio in proportion to the lysine concentration (Owen et al., 1997). Applying the concept of the ideal protein ratio for practical swine diet formulation is useful because using lysine as a reference amino acid makes it possible to simplify practical feed formulation; if the lysine requirement is known, the requirement for other essential amino acids can be calculated accurately in formulation of swine diets (Chung and Baker, 1992a).

The Optimal Ratios Among Essential Amino Acids

Since the British ARC (1981) proposed an ideal protein for swine, there have been numerous efforts to modify the ideal protein pattern to more closely meet the optimal ratios of essential amino acids relative to lysine (Wang and Fuller, 1989; Chung and Baker, 1991; Chung and Baker, 1992a) that are needed by swine to obtain maximum

growth performance. In 1992, Chung and Baker conducted a study to improve the ideal amino acid pattern for 10-kg pigs and to compare the resulting ideal protein with the Wang and Fuller ideal amino acid pattern (WFIP, Wang and Fuller, 1989), the Illinois final amino acid pattern (IFP, Chung and Baker, 1991), the Illinois ideal amino acid pattern (IIP, Chung and Baker, 1992a) and the National Research Council amino acid requirement pattern (NRCP, NRC, 1988) for 10-kg pigs. Whereas the NRCP and IIP included arginine and histidine, the WFIP did not include these two amino acids. These four ideal protein patterns compared in this study and the ARC (1981) ideal protein pattern are presented in Table 2.2.

Table 2.2. Comparison of five amino acid patterns relative to lysine.

	Amino acid pattern (% of lysine)[a]				
Amino acid	ARC (1981)	NRCP (1988)	WFIP (1989)	IFP (1991)	IIP (1992)
Lysine	100	100	100	100	100
Arginine[b]	-	42	-	42	42
Histidine[c]	33	26	-	27	32
Isoleucine	55	56	60	57	60
Leucine	100	74	110	87	100
Met. + Cys.	50	52	63	61	60
Phe. + Tyr.	96	81	120	83	95
Threonine	60	59	72	57	65
Tryptophan	15	15	18	14	18
Valine	70	59	75	60	68

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

[b] Arginine values were not specified in the ARC (1981) and the WFIP (1989) profile.

[c] A histidine value was not specified in the WFIP (1989) profile.

In the first trial, regardless of which amino acid pattern was fed, pigs had similar ADG, ADFI, and feed efficiency when pigs had ad libitum access to experimental diets with essential amino acid levels established above the NRC (1988) requirements (Chung and Baker, 1992a). In a second experiment (Chung and Baker, 1992a), all levels of essential and non-essential amino acids were decreased to 50% of levels present in Experiment 1. When pigs were allowed ad libitum access to these diets, ADG of pigs receiving IIP was greater than that of pigs fed IFP or NRCP, but similar ADG was observed in pigs fed IFP, WFIP, and NRCP. In a third experiment (Chung and Baker, 1992a) to determine the efficiency of nitrogen utilization of the four essential amino acid patterns in pigs equally receiving the same experimental diets supplied in Experiment 2, nitrogen utilization of pigs fed NRCP was less than that of pigs fed IFP, IIP, and WFIP. In addition, nitrogen retained per gram of nitrogen intake from essential amino acids was greater for IIP than for either IFP or WFIP. From these results, the researchers suggested that IIP was superior to either the NRCP or WFIP for pigs weighing 10 to 20 kg.

In 1998, the NRC developed an ideal protein pattern primarily from experiments specifically designed to identify the optimal ratios among essential amino acids in swine diets. In this publication, the ideal protein pattern is divided into three subdivisions, one for maintenance, one for protein accretion, and one for milk synthesis. These three ideal protein patterns, along with a pattern for body tissue protein accretion are presented in Table 2.3. Among these patterns, arginine is not listed in the ideal pattern for maintenance. The NRC (1998) explains arginine is not required for maintenance in swine and that the value of –200% of arginine for maintenance is established to reflect the fact that arginine synthesis can satisfy all the maintenance needs and some of the needs for

protein accretion. In addition, the NRC (1998) also explains that the maintenance ratio for histidine is established equal to the ratio for protein accretion because the maintenance requirement for histidine has not been determined.

Table 2.3. Ideal ratios of amino acids to lysine for maintenance, protein accretion, milk synthesis, and body tissue[a].

Amino acid	Maintenance	Protein Accretion	Milk Synthesis	Body Tissue
Lysine	100	100	100	100
Arginine[b]	-200	48	66	105
Histidine[c]	32	32	40	45
Isoleucine	75	54	55	50
Leucine	70	102	115	109
Methionine	28	27	26	27
Met. + Cys.	123	55	45	45
Phenylalanine	50	60	55	60
Phe. + Tyr.	121	93	112	103
Threonine	151	60	58	58
Tryptophan	26	18	18	10
Valine	67	68	85	69

[a] The NRC (National Research Council), 1998.

[b] The value of –200 was set to reflect the fact that arginine synthesis can satisfy all the maintenance needs and some of the needs for protein accretion.

[c] The maintenance requirement for histidine has not been determined, and so the maintenance ratio was set equal to the ratio for protein accretion.

Ratios of Essential:Non-essential Amino Acids

Because the ideal protein concept implies that a protein is perfectly balanced in terms of its amino acid content and its supply of non-essential nitrogen (Cole, 1980), it is important to identify not only the optimal ratios among essential amino acids but also the ratios of essential:non-essential amino acids to achieve maximum growth efficiency for

swine. However, research estimating the optimal ratios of essential:non-essential amino acids to acquire maximum growth performance for swine is limited. Mitchell, Jr. et al. (1968) reported that in young pigs, dietary nitrogen was most efficiently used when essential and non-essential amino acids each supplied about 50% of the total dietary nitrogen. Another study by Wang and Fuller (1989) suggested that the greatest efficiency of nitrogen retention was observed when the ratio of essential:non-essential amino acid was 50:50 or 57:43. These investigators concluded that the optimum ratio of essential:non-essential amino acids was extrapolated to be 45:55. Similar experimental results were obtained by Roth et al. (1993), who carried out a study using 50-kg female pigs to evaluate the extent to which the dietary protein supply can be reduced in order to combine maximum nitrogen retention with minimum nitrogen excretion. These researchers indicated that the daily protein supply could be depressed up to 2 g N/kg $LW^{0.75}$ to combine maximum nitrogen retention with minimum nitrogen excretion and further reduction of protein supply decreased nitrogen excretion as well as nitrogen retention implying a deficiency of nonessential amino acids. In this study, these authors concluded that based on regression analysis, a minimum supply of crude protein of 12.6 g/kg $LW^{0.75}$ was derived with a proportion of essential:non-essential amino acids of 47:53.

Nonessential Nitrogen

Consideration of nonessential nitrogen in balancing rations on an ideal protein basis for swine is also important because it is needed for the synthesis of nonessential amino acids. In addition, a deficiency of nonessential nitrogen in swine diets even which

contain synthetic amino acids formulated on an ideal protein basis may cause poor performance. Fickler et al. (1994), who conducted a study to compare a diet 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) to a control diet (containing grains, soybean meal, fish meal, and skim milk) as the source of amino acids, reported that pigs fed the chemically defined diet had a 24% decrease in growth rate and a 14% lower absolute nitrogen retention as compared to those fed the control diet. These investigators suggested that the amount of dispensable amino acids in this chemically defined diet should be raised and the pattern of indispensable amino acids should be improved in order to increase growth performance and nitrogen retention. On the other hand, Roth et al. (1994) suggested that in growing pigs, alanine, aspartic acid, glycine or serine were completely non-essential, whereas arginine, glutamic acid, or proline were essential and must be provided in the diet in a certain amount. In this study, these researchers evaluated the effect of omission of alanine, arginine, aspartate, glutamic acid, glycine, proline, or serine from a chemically defined diet on the nitrogen metabolism of young pigs with an average of 14 kg live weight. When each amino acid was omitted, it was substituted by the remaining amino acid in the same proportions so that it was equal in nitrogen to the control diet including a complete mixture of these amino acids. Whereas the omission of alanine, aspartic acid, glycine, or serine from the control diet did not affect nitrogen accretion and nitrogen utilization, the omission of arginine, glutamic acid, or proline resulted in a significant decrease in nitrogen accretion by 50%, 6%, and 8%, respectively.

Synthetic Amino Acids (Crystalline Amino Acids)

General

The amino acid requirement of swine can be supplied by natural intact proteins such as those contained in feed ingredients in the diet or they can be furnished by synthetic (crystalline) amino acids that are produced by fermentative synthesis, chemical synthesis, or chemical extraction processes. Chemical synthesis yields the DL-racemic mixture (1:1 ratio of D- and L- isomers), whereas fermentative synthesis and chemical extraction processes produce the L-isomer (Baker, 1994). In general, it is much cheaper to use the natural intact proteins to provide the requirement for amino acids by swine, but crystalline sources of some amino acids are now available at prices that often merit their inclusion in swine diets (Lewis, 1991). Crystalline amino acids can be added to low-protein swine diets to overcome potential amino acids deficiencies (Tuitoek et al., 1997) and to improve the amino acid balance in the diet in order to optimize swine production. In swine production, the reduction of nitrogen excretion is related to the protein content and amino acid balance of the diet, because the oversupply of protein and an imbalance of amino acids are mainly excreted in urine (Valaja et al., 1993). Thus, the addition of optimal synthetic amino acids to low-protein diets is one way to decrease the nitrogen excretion per unit of pork produced (Lenis, 1989; Carter, 1996), and the reduced nitrogen excretion results in a more favored environment in swine production.

Feeding Value of Synthetic (Crystalline) Amino Acids as the Source of Amino Acids in Swine Diets

There have been several attempts to determine whether similar growth performance could be obtained when crystalline amino acids were substituted for natural intact protein as the source of amino acids in swine diets. de Rodas et al. (1997) indicated that in segregated early-weaned pigs, replacement of amino acids in whey protein concentrate by an ideal mixture of crystalline amino acids resulted in reduced growth performance. Davis et al. (1997) also reported that in conventionally weaned pigs, substitution of whey protein concentrate with crystalline amino acids resulted in depressed average daily gain and gain:feed ratio during Phase 1 (day 0 to 14). Likewise, Fickler et al. (1994) reported, on the basis of similar energy intake, a 24% decrease in growth rate and a 26% increase in energy expenditure of 10 to 15 kg pigs fed a chemically-defined diet containing essential amino acids as recommended by Chung and Baker (1992a) and a complete mixture of nonessential amino acids when compared to those fed a control diet containing grains, soybean meal, fish meal, and skim milk as the source of amino acids.

The use of supplemental synthetic amino acids to obtain optimal growth response in natural intact low-protein diets for swine has been conducted by a number of investigators. Kephart and Sherritt (1990) observed that in growing pigs, with an average initial weight of 23.7 kg, fed a low-protein (10.9% CP) corn soybean meal based diet with a selected number of crystalline essential amino acids (i.e., L-lysine·HCl, L-

tryptophan, L-threonine, L-isoleucine, DL-methionine, and L-valine) had slower growth rates than those fed high-protein (16.9% CP) corn-soybean meal-based diet without crystalline amino acid supplementation. However, Spiekers et al. (1991) reported that pigs weighing 10 to 25 kg fed a high soybean meal diet with no supplemental synthetic amino acids had similar growth responses when compared to those fed a low soybean meal diet with supplemental synthetic amino acids (i.e., lysine, methionine, threonine, tryptophan, and isoleucine).

Brudevold and Southern (1994) conducted three experiments to evaluate the use of supplemental crystalline amino acids in low-protein sorghum-soybean meal diets for 10 to 20-kg pigs. In the first two experiments, pigs had ad libitum access to feed but in the third experiment pigs were fed twice daily an amount estimated to be approximately that of ad libitum intake in this study. In the first two trials, pigs fed the low-protein (12% CP) diet with addition of crystalline amino acids (i.e., lysine, threonine, glutamic acid, methionine, histidine, isoleucine, tryptophan, and valine) had similar performance to pigs fed a 21.81% crude protein diet without supplemental crystalline amino acids. However, in the third trial, pigs fed the 21.18% crude protein positive control diet had greater growth rates than pigs fed the low-protein (12% CP), crystalline amino acid diet. These researchers suggested that the disparity in the results of these trials were derived from the fact that the low-protein, crystalline amino acid diet may be marginally deficient in some nutritional factor, which when added would result in maximum performance. Limit feeding pigs a nutritionally deficient diet can result in lower performance than that of pigs allowed ad libitum access to this deficient diet. Similar results were also obtained by Corley and Easter (1980) who assessed the effect of synthetic lysine and tryptophan

supplementation of low-protein diets for growing pigs. In the first experiment of this study, they observed that growing pigs fed a 10% crude protein corn-soybean meal diet with addition of .48% L-lysine·HCl and .02% L-tryptophan had inferior growth performance as compared to those fed a 16% protein corn-soybean meal control diet. However, in a second experiment, they found that when pigs were fed a 12% crude protein corn-soybean meal diet supplemented with .25% L-lysine·HCl and .02% L-tryptophan, gain and gain:feed ratio were similar to pigs fed a 16% corn-soybean meal diet. The authors speculated that the differing results between experiment 1 and 2 were caused by the fact that total nitrogen in the 10% crude protein diet limited the response to supplementation of synthetic amino acids.

Whey as an Ingredient for Weanling Pigs

General

After weaning (between 3 and 4 weeks of age), pigs are transferred from a liquid diet to a solid nursery diet. During this period, pigs experience poor performance. This response is related to inadequate digestive development resulting in poor utilization of nutrients in the starter diet (Leibbrandt et al., 1975). Other factors involved in poor postweaning performance include low disease resistance or depressed immune response (Inoue et al., 1978) and environmental stress (Kelly, 1980).

The transition toward a mature enzyme profile that can effectively hydrolyze the complex cereal grain molecules does not seem to develop as rapidly in early-weaned (less

than 21 days of age) pigs as it does in late-weaned (more than 21 days of age) pigs (Lepine et al., 1991). Therefore, there have been many attempts to overcome this digestive insufficiency by supplementing weanling pig diets with more easily digested milk products, such as whey. Graham et al. (1981) evaluated the effects of 20% dried whey or 15% dried skim milk additions to cereal grain-based diets on postweaning performance and digestive enzyme activities of 2 week-old weanling pigs. These authors reported that both milk products, but especially dried whey, improved pig performance and amylase and protease enzyme activities in the pancreas, small and large intestine contents, and in the small intestine mucosa. In addition, these researchers indicated that total lactase activity in the small intestinal mucosa and both the small and the large intestine contents was greater when either milk product was provided in the diet. Similarly, Owsley et al. (1986a) reported that pigs consuming a corn-soybean meal-based diet with 20% dried whey had higher levels of trypsin and chymotrypsin in the intestinal contents and greater intestinal amylase activities than pigs consuming a corn-soybean meal based-diet without whey. Moreover, Lindemann et al. (1986) found that pigs fed a corn-soybean meal-based diet with 20% dried whey had larger pancreases at slaughter and greater, but not significant, mean pancreatic enzyme (lipase, amylase, chymotrypsin, and trypsin) activity values per gram of pancreas than pigs fed corn-soybean meal-based diets without whey.

Because whey has a relatively high digestibility (Lepine et al., 1991) and provides a high nutritive value due to its relatively complete amino acid profile (Smith, 1976), it is commonly used as an ingredient in young pigs diets to improve growth performance of postweaning pigs. Tokach et al. (1989) reported that pigs fed diets containing milk

products such as dried whey, lactose, lactalbumin, and lactose + lactalbumin had significantly higher apparent dry matter, nitrogen, and energy digestibility than pigs fed a corn-soybean meal diet. Owsley et al. (1986b) found an increase in dry matter and energy digestibility with the addition of 20% dried whey to a corn-soybean meal based diet for young pigs.

Nutrient Composition of Whey

Whey, which contains water, proteins (amino acids), lactose, minerals, enzymes, water-soluble vitamins, and traces of fat, is the watery part of milk separated from the curd in the process of cheese making. In the process of cheese making about 10 kg of milk are used to attain 0.5 to 1 kg of cheese and the whey that remains is approximately 7% dry matter and consists of about 90% of the lactose, 20% of the protein, 40% of the calcium, and 43% of the phosphorus originally in the milk (Leibbrandt and Benevenga, 1991).

Whey proteins, which are those proteins left in whey after the manufacture of cheese and have relatively complete amino acids profile, consist of three major protein fractions, lactalbumin, proteose-peptone, and immunoglobins. Lactalbumin, the greatest fraction, contains α-lactalbumin, β-lactoglobulin, and serum albumin (Leibbrandt and Benevenga, 1991). The amino acids profiles of whey proteins are unusual in having a relative surplus of the majority of the essential amino acids including lysine and the combined sulfur-containing amino acids (Smith, 1976).

Because whey protein has a greater portion of lysine and several other essential amino acids compared with cereal grains such as rice, corn meal, and wheat (Chan et al., 1976), it is an excellent supplement to cereal grains which contain lower quality proteins (Womack and Vaughan, 1972; Forsum, 1979). Thus, diets based on corn, in conjunction with whey, should minimize the total protein needed to satisfy essential amino acids requirements for growing-finishing pigs (Leibbrandt and Benevenga, 1991).

The Main Forms of Whey as an Ingredient of Starter Pig Diets

In general, liquid whey, dried whey, and whey protein concentrate (WPC) are the main forms of whey which can be incorporated into the diets for young, early-weaned pigs as a suitable supplemental source of proteins or amino acids.

Liquid whey, the serum or watery part of milk that separates from the curd during cheese processing, can be commonly available in two types: sweet whey and acid whey. Whereas sweet whey is effluent from whole milk following the manufacture of natural or rennet cheeses (Swiss, Munster, Chaddar, Monterey Jack, etc.) and processed cheese, acid whey is produced from acid casein processing of skim milk during cottage, pot, or farmer cheese making (Leibbrandt and Benevenga, 1991).

Dried whey is a by-product of cheese manufacturing and one kilogram of dried whey includes approximately equivalent amounts of nutrients to 14 kilograms of liquid whey. Dried whey can be commonly used at the levels of 10 to 30% in the diets of young, early-weaned pigs (Seerley, 1991). However, Ekstrom et al. (1975) reported that as much as 40% dried whey could be added to growing pig diets without depressing performance.

Ultrafiltration refers to as a pressure activated process using semipermeable polymeric membranes to separate molecular or colloidal materials dissolved or suspended in a liquid phase (Smith, 1976). Ultrafiltering whey can increase the concentration of protein and other solids in the retentive fraction (McDonough et al., 1974). This fraction is often called WPC. Including ultrafiltration, WPC can be prepared by different processes such as electrodialysis, gelfiltration, metaphosphate complex, carboxymethyl cellulose complex, iron complex, and ethanol precipitation (Smith, 1976).

Feeding Value of Whey as a Source of Protein (Amino Acids) or Lysine in Starter Diets of Pigs

There have been several attempts to evaluate the feeding value of whey as a source of protein (amino acids) or lysine in young pig diets. Cieslak et al. (1986) evaluated the feeding value of fresh sweet liquid whey as a protein supplement to maize for growing pigs. These researchers indicated that dried whey is better than soybean meal as a supplemental protein source to maize-based diets for growing pigs because of the higher lysine content of whey compared to that of soybean meal. Cinq-Mars et al. (1986) reported that WPC could be used in liquid form as a source of protein and energy up to a level of 33.7% (as DM basis) in corn-soybean meal diets. A study by Davis et al. (1996a, 1996b), who evaluated the effect of increasing level of dietary WPC (77% crude protein) as a lysine source on pig performance during Phase 1 (day 0 to 14 postweaning) of the nursery period, indicated that the lysine requirement for maximum performance of Phase 1 nursery pigs was at least 1.60%, and ADG and G/F improved with increasing dietary

lysine when WPC was the lysine source. de Rodas et al. (1997) reported that in SEW pigs, substitution of the amino acid component in WPC with an ideal mixture of synthetic amino acids resulted in depressed growth performance. Similarly, Davis et al. (1997) observed that in conventionally weaned pigs, replacement of amino acids in WPC with crystalline amino acids resulted in reduced performance. In addition they also indicated that protein source in the basal diet appears to impact response to crystalline amino acids addition.

The Nutrient Factor(s) Other than Lysine in Dried Whey that Improve the Postweaning Performance of Early Weaning Pigs

There have been many studies which reported that the addition of dried whey as an ingredient to a starter diet improved performance of pigs weaned 3 to 4 weeks of age (Miller et al., 1971; Cera and Mahan, 1985; Goodband and Hines, 1987; Lepine et al., 1991; Mahan et al., 1993). Thus, there have been many attempts to identify the reasons why early weaned pigs have improved performance when dried whey is added as an ingredient in starter rations.

There have been some studies which suggest that nutrient factors other than lysine in dried whey enhance postweaning growth performance of early-weaned pigs. Mahan et al. (1993) reported that in weanling pigs lysine was not a limiting factor in either a corn-soybean meal or corn-soybean meal-dried whey diet formulated to either .95% or 1.10%, and another factor in dried whey was assumed to be responsible for its growth promotion effect. Tokach et al. (1989) reported that both the carbohydrate (lactose) and protein

(lactalbumin) fractions of dried whey were important factors that improved growth performance of early-weaned pigs when dried whey was fed. These authors also found that when both fractions were present in the diet there were no additive effects. However, Mahan (1992) suggested that the lactose not the lactalbumin component of dried whey is the primary factor that stimulated growth performance of young pigs. In addition, Lepine et al. (1991) suggested that a component of dried whey other than lysine (e.g., lactose) was the most limiting nutrient in corn-soybean meal based diet, but when dried whey was supplemented, growth responses to crystalline lysine occurred during the latter phase of the starter period. These researchers also suggested that a highly available carbohydrate source such as lactose might be necessary to achieve maximum growth responses in weanling pigs fed a corn-soybean meal diet supplemented with L-Lysine·HCl.

The Effects of Dietary Cation-Anion Balance on Growth Performance or Acid-Base Status in Growing Pigs

General

Dietary cation-anion balance (DCAB) refers to the balance of fixed cations and fixed anions (i.e., ions that are not metabolized) in the diet (Tucker et al., 1991). The calculation of DCAB for swine is based on the fixed cations minus the fixed anions in the diet. The calculation of DCAB is typically calculated by using the equation of $(Na^+ + K^+) - (Cl^-)$ (Mongin, 1981; Patience et al., 1987; Block; 1991), and it is expressed in

milliequivalents (mEq) per 100 g or per kilogram of diet. Patience and Wolynetz (1990), however, suggested that this equation ($Na^+ + K^+ - Cl^-$) may be conceptionally incomplete because it considers only the monovalent mineral ions, and it does not speculate on the major determinants of the acid or alkaline contributions from calcium, magnesium, sulfate, and phosphate in the diets. These researchers also indicated that dietary undetermined anion, calculated as $(Na^+ + K^+ + Ca^{++} + Mg^{++}) - (Cl^- + PO_4^{---} + SO_4^{--})$, is an important dietary component with the potential to change pig performance and health. However, the inclusion of dietary undetermined anion that is a major determinant of the acid or alkaline contributions (i.e., Ca^{++}, Mg^{++}, SO_4^{--}, and PO_4^{---}) in the equation for DCAB in swine has been reported on a limited basis.

The fixed cations and fixed anions can determine the acid-base status in biological fluids (Stewart, 1978) of the animal and directly or indirectly affect osmotic pressure, Na^+ -K^+ pumping, acid-base balance, cell membrane integrity, buffering systems, kidney function, and hormone and enzyme kinetics. According to McDonald et al. (1995), changes in the cation and anion balance affect the metabolism of energy, amino acids, vitamin D, and calcium; thus, it can produce an effect on the efficiency of growth of all species.

Relationship between Dietary Cation and Anion Balance and Growth Performance or Acid-Base Status in Growing Pigs

There have been some controversial reports concerning the relationship between dietary electrolyte balance and growth or acid-base status in swine. In 1966, Leibholz et al. reported that 10 to 20 g/kg of potassium acetate (CH_3COOK) enhanced growth rate and feed efficiency in weanling pigs fed protein deficient (16% CP), corn-soybean meal-based diets. In addition, Austic et al. (1983) observed that growth performance of young growing pigs fed lysine deficient diets responded to sodium bicarbonate ($NaHCO_3$) or potassium bicarbonate ($KHCO_3$) during a 28-d experimental period. Patience et al. (1987) reported also that addition of 25.9 g/kg $NaHCO_3$ to a corn-corn gluten meal-soybean meal-based diet (17.6% CP) in which both lysine and tryptophan were limiting significantly improved growth and feed intake. Furthermore, Haydon et al. (1990) reported that feed intake and weight gain in growing-finishing pigs can be enhanced during periods of heat stress by dietary electrolyte ($Na^+ + K^+ - Cl^-$ mEq/kg of feed) modification. These authors speculated that this improvement in performance is presumably due to increased blood buffering capacity.

However, other researchers have reported that growth performance was not affected in pigs fed lysine deficient diets with potassium salts from potassium chloride (KCl), potassium acetate (CH_3COOK, Wahlstrom et al., 1983), potassium carbonate (K_2CO_3) (Zimmerman, 1982; Froseth et al., 1983), and K_2CO_3 or $KHCO_3$ (Miller et al., 1984). In addition, Brudevold and Southern (1994) reported that $NaHCO_3$ addition did

not affect gain, feed intake, feed efficiency, and apparent nitrogen digestibility of 10 to 20 kg pigs fed low-protein (12% CP), crystalline amino acid-supplemented sorghum-soybean meal-based diets.

There have been attempts to identify the DCAB range that results in optimum growth performance in growing pigs, but the range is varied. Austic et al. (1983) indicated that in young growing pigs fed a lysine deficient diet that optimum performance was detected in the range of 100-300 mEq/kg of DCAB ($Na^+ + K^+ - Cl^-$), although none of the differences were significantly different. On the other hand, Utley et al., (1987) reported that in growing pigs fed corn-soybean meal-based diets, DCAB ($Na^+ + K^+ - Cl^-$) of 250 mEq/kg in diets may improve ADG over dietary levels of 100 and 400 mEq/kg during high ambient temperatures. Similar results were obtained by Haydon et al. (1990) who reported that in growing pigs (25 to 50 kg) fed corn-soybean meal-based diets, daily feed intake and ADG tended to increase at a more rapid rate from 25 to 250 mEq/kg of DCAB ($Na^+ + K^+ - Cl^-$) but remained essentially constant or decreased further when DCAB increased to 325 or 400 mEq/kg during high ambient temperatures. In contrast, Patience et al. (1987) reported that diets containing a DCAB ($Na^+ + K^+ - Cl^-$) varying from 0 to 341 mEq/kg of dry matter showed similar growth performance, but growth and feed intake in growing pigs were improved as compared with diets containing –85 mEq/kg of dry matter.

Plasma Urea Nitrogen (PUN)

Factors Affecting Plasma Urea Nitrogen (PUN)

Urea, which is the major end product of protein metabolism, is formed almost exclusively in the liver, released into the blood stream, and excreted into the urine by the kidney. Eggum (1970) identified three factors affecting plasma urea nitrogen (PUN) concentrations: 1) there exists a positive correlation between the dietary protein content and the plasma urea concentration; 2) there is an inverse correlation between the dietary protein quality and the plasma urea concentration; and 3) the plasma urea content increases for the first 3-4 h after feeding and then reaches a plateau during a 5-h sampling period. However, there are some controversial reports on PUN concentrations with sampling times after feeding in pigs. Malmlof et al. (1989) reported that in growing pigs PUN peaked at 4 and 5 h after feeding during an 8-h sampling period. Malmlof et al. (1990) observed also in growing pigs that PUN reached a maximum at 4 h after feeding during a 16-h sampling period. However, Cai et al. (1994) reported that pigs fed twice daily had a postprandial peak of PUN at 4 h following feeding but pigs that had free access to feed had constant concentrations of PUN with only a slight fluctuation during the day and night. Thus, sampling time after feeding probably does not affect PUN concentrations if pigs have ad libitum access to feed. In general, among the three factors affecting PUN concentrations, the protein quality should be the indisputable influence on plasma urea concentration because it is possible to remove the effects of both protein content and time after feeding by standardizing the technique (Eggum, 1970).

Plasma Urea Nitrogen Concentration as a Predictive Indicator of Amino Acid Status

The highly negative correlation between dietary protein quality and plasma urea nitrogen concentration was first utilized to evaluate amino acid requirements of humans (Taylor et al., 1974) and pigs (Brown and Cline, 1974). Since then, measurement of PUN concentration has become a successful predictor of amino acid status in swine and other non-ruminant animals.

Plasma urea nitrogen concentrations increase when there is amino acid imbalance in the diet. If an amino acid is limiting or at deficient levels, this amino acid restricts the utilization of other non-limiting or sufficient levels of amino acids for protein synthesis. Then, these surplus amino acids are utilized for urea synthesis resulting in increased PUN concentrations. Kumta and Harper (1961) reported that when dietary amino acid balance is improved with addition of the first limiting amino acid, PUN concentrations are reduced. In addition, Grobach et al. (1985) reported that addition of limiting amino acid to diets with imbalanced amino acid patterns resulted in a reduction in PUN concentrations. Moreover, Brown and Cline (1974) also reported that the addition of the first limiting amino acid to an amino acid deficient diet resulted in a decrease of PUN concentrations. The authors speculated that the addition of the first limiting amino acid in the amino acid deficient diet in this study should support a higher level of protein synthesis and, hence, a lower level of amino acids would need to be catabolized, thus resulting in depressed PUN concentrations. The reduction in PUN concentration presumably reflected a more efficient total nitrogen utilization and, thus, depressed urea synthesis in pigs fed adequate amino acid concentrations.

On the other hand, PUN concentrations of pigs tend to be increased when dietary amino acid concentrations greater than the requirement are fed (Lewis et al., 1977, 1981; Coma et al., 1995). This observation is presumably caused by the fact that feeding dietary amino acid concentrations greater than the requirement results in an excess of amino acids that are catabolized and thus, the enhanced urea synthesis rate results in greater PUN concentrations (Coma et al., 1995). However, concentration of PUN tends to be much lower when diets are formulated on an ideal protein basis. Lopez et al. (1994) and Davis (1996a) found that PUN concentrations of pigs fed diets containing synthetic amino acids formulated on an ideal protein basis was lower than that of pigs fed diets containing natural intact protein sources.

There is a highly significant negative correlation between energy intake and PUN concentration. Cai et al. (1995) reported that in pigs PUN concentrations were decreased with increasing energy intake. The researchers suggested that the decreased PUN concentrations resulting from increasing energy intakes indicated an improved utilization of dietary N for protein accretion as energy intake increased. At low energy intakes, amino acids were oxidized to furnish energy for maintenance whereas at increasing energy intakes, a decreasing amount of amino acids is oxidized and an increasing amount is incorporated into body proteins. Similar observations were obtained in sows (Brendemuhl et al., 1987) and beef heifers (McShane et al., 1989).

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CHAPTER III

THE EFFECT OF INCREASING WHEY PROTEIN CONCENTRATE (77% CP) AS A LYSINE SOURCE ON PERFORMANCE OF SEGREGATED EARLY-WEANED PIGS

ABSTRACT

Two growth trials involving 140 weanling pigs were conducted to determine the dietary lysine requirement to maximize growth performance in segregated early-weaned pigs. Pigs were housed in an environmentally-controlled off-site nursery. In Experiment 1, 60 pigs (14±2 days of age and 4.2 kg body weight) penned in groups of three (5 pens per treatment) were used to evaluate four dietary lysine levels (1.30, 1.45, 1.60, and 1.75%). In Experiment 2, 80 pigs (14±2 days of age and 4.5 kg body weight) penned in groups of four (4 pens per treatment) were used to evaluate five dietary lysine levels (1.30, 1.45, 1.60, 1.75, and 1.90%). In both experiments, diets contained corn, lactose, whey, steam-rolled oats (10.0%), fish meal (8.0%), dried skim milk (5.0%), spray-dried plasma protein (5.0%), egg protein (4.0%), and soy oil (3.0%). Cornstarch and sucrose were replaced by whey protein concentrate (WPC) to increase lysine levels in each experimental diet. Calculated composition of lactose in all diets was 24%. Experimental diets were fed from day 0 to 14 postweaning, and then all pigs were fed a common transition diet (1.40% lysine) from day 14 to 28 and a Phase 2 diet (1.35% lysine) from day 28 to 42. Pigs in Experiment 2 were bled on day 14, 28, and 42 postweaning to

determine plasma urea nitrogen concentration. In Experiment 1, from d 0 to 7 and 0 to 14 postweaning, average daily gain (ADG) and gain:feed (G:F) were increased (P<.01) linearly as dietary lysine level increased and were maximized at 1.75% dietary lysine. In Experiment 2, in the same period, ADG and G:F increased (P<.06) linearly with increasing dietary lysine level and were maximized at 1.90% lysine. Concentrations of plasma urea nitrogen increased linearly (P<.01) with increasing dietary lysine. These results suggest that segregated early-weaned pigs require at least 1.75% of total dietary lysine to optimize growth performance from day 0 to 14 postweaning.

INTRODUCTION

This trial is the first step of a multi-phase study with the overall objective to determine the potential for substituting synthetic amino acids for dietary protein in segregated-early weaned (SEW) nursery diets. Segregated early weaning implies a procedure to control infectious disease with the main purpose to improve the efficiency of swine production. In a segregated early weaning system, pigs are weaned at an earlier age than the conventional weaning age and are transmitted to an off-site nursery separate from the sow herd to avert and minimize the vertical transmission of various infectious diseases (Dritz et al., 1994). Recent trends in the swine industry have been toward earlier weaning with many systems routinely weaning pigs as early as 10 to 15 days of age in a segregated early weaning system and as early as 19 to 21 days of age in a traditional production system.

Research evaluating the lysine requirement in segregated early-weaned pigs has been limited. However, several experiments (Stahly et al., 1994; Owen et al., 1994) with segregated early-weaned pigs suggest that the lysine requirement is much higher than levels recommended by NRC (1988). In addition, lysine levels in diets typically used in the swine industry are much higher than previously recommended. Furthermore, Williams et al. (1994) reported that pigs weighing from 6.0 to 27.0 kg with low immune system activation had a greater capacity for protein deposition and a greater lysine requirement (1.50% total lysine) than those with high immune system activation (1.20% total lysine) to maximize performance. They found that pigs with low immune system activation had a greater capacity for proteinaceous tissue growth and greater dietary amino acids needs than pigs with high immune system activation.

In typical feed formulations that utilize natural feed ingredients, there is usually an excess of many dispensable and indispensable amino acids. These excess amino acids have been suggested to depress animal performance, although no evidence for this is available for SEW pigs. In SEW nursery diets, the substitution of amino acids for protein offers the potential for improving performance as well as decreasing the inclusion level of expensive protein sources. Therefore, studies concerning the potential for replacing amino acids available at feed grade prices (lysine, methionine, threonine, and tryptophan) in the diet of pigs weaned as early as 12 days of age are needed. First, the lysine requirement for segregated early-weaned pigs needs to be determined in our system. Therefore, the objective of this initial study was to determine the lysine requirement for segregated early-weaned pigs fed a high-nutrient dense diet using whey protein concentrate as a source of amino acids.

MATERALS AND METHODS

Two trials involving a total of 140 weanling pigs (Yorkshire, Hampshire, and Yorkshire x Hampshire) were conducted to evaluate the dietary lysine requirement to maximize growth performance in segregated early-weaned pigs. In Experiment 1, a total of 60 pigs (14±2 days of age and 4.2 kg average initial body weight) was sorted by weight, and divided into five groups (blocks). Weight groups contained 12 pigs each. Pigs within each weight group were allotted into four equal subgroups (three pigs per pen) with stratification based on sex and litter. The pens within each of the five weight groups were randomly assigned to four dietary treatments (5 pens/treatment). Four dietary levels of lysine were used to estimate the lysine requirement of segregated early-weaned pigs. The four dietary lysine levels were achieved by substituting whey protein concentrate (WPC) for cornstarch and sucrose to obtain 1.30, 1.45, 1.60, and 1.75% lysine (Table 3.1). From day 0 to 14 postweaning, all four diets contained 12.0% whey, 10.0% steam-rolled oats, 8.0% select menhaden fish meal, 5.0% dried skim milk, 5.0% spray-dried plasma protein, 4% egg protein, and 3.0% soy oil. Whey protein concentrate varied in the diets from 0% in the control diet (1.30% lysine) to 9.61% in the diet containing the highest level of lysine (1.75%). The four experimental diets contained .1% L-lysine·HCl, and threonine and methionine were added to diets to maintain an ideal protein ratio according to Chung and Baker (1992). Lactose, calcium, and phosphorus levels were maintained constant in all four experimental diets at 24%, .90%, and .79%, respectively (Table 3.2).

In Experiment 2, a total of 80 pigs (14±2 days of age and 4.5 kg) was sorted by weight and divided into four weight groups (blocks). Weight groups contained 20 pigs each. Pigs within each weight group were allotted into five equal sub groups (four pigs per pen) with stratification based on sex and litter. The pens within each of the four weight groups were randomly assigned to five dietary treatments (4 pens per treatment). Five dietary levels of lysine were used to determine the lysine requirement of segregated early-weaned pigs. The five dietary lysine levels were attained by replacing cornstarch and sucrose with WPC to obtain concentrations of 1.30, 1.45, 1.60, 1.75, and 1.90% lysine (Table 3.5). From day 0 to 14 postweaning, all five diets included 21.96% whey, 10.0% steam-rolled oats, 8.0% select menhaden fish meal, 5.0% dried skim milk, 5.0% spray-dried plasma protein, 4% egg protein, and 3.0% soy oil. Whey protein concentrate varied in the diets from 0% in the control diet (1.30% lysine) to 12.60% in the diet containing the highest level of lysine (1.90%). Methionine was added to diets to maintain an ideal protein ratio according to Chung and Baker (1992). Lactose, calcium, and phosphorus levels were maintained constant in all five experimental diets at 24%, .92%, and .80%, respectively (Table 3.6).

Pigs in both trials were fed a common Transition diet (1.40% lysine) from day 14 to 28 and a Phase 2 diet (1.35% lysine) from day 28 to 42 postweaning to monitor any carry over effect from experimental diet fed during the first two weeks of the experiment. All diets met or exceeded National Research Council (NRC, 1988) guidelines. Diets were pelletted with a 100-horsepower pellet mill (California Pellet Mill, San Francisco, CA) equipped with a 3.97-mm die. From day 0 to 14, a sample of each treatment diet in

both experiments was taken for analysis of the content of crude protein and amino acids. A representative sample of each diet was collected and analyzed for amino acids according to the AOAC (1984) methods at the Experiment Station Chemical Laboratories at the University of Missouri. Briefly, samples were acid hydrolyzed with degassed 4.2N NaOH for 4 h at 145°C. For sulfur amino acids, samples were pre-oxidized with performic acid. A Beckman 6300 amino acid analyzer (integrated HPLC system) with a cation exchange resin derivatization with ninhydrin was used to quantify the amino acids in the samples. Amino acid analyses were done singly, and a standard was included with samples. The results of amino acid analysis in the complete diets are shown in Table 3.3. Pigs were housed in an environmentally-controlled off-site nursery in elevated pens (1.09 m x1.52 m) with woven wire flooring. The initial temperature of 31°C was subsequently decreased 1°C per week. Pigs in each pen had ad libitum access to one nipple waterer and a three-hole feeder. Pig body weight and feed intake were determined weekly to evaluate average daily gain (ADG), average daily feed intake (ADFI), and gain:feed (G:F). Blood samples were taken via anterior vena cava puncture on d 14, 28, and 42 of the experiment. Samples were centrifuged, and serum was harvested and stored at -20°C until it was assayed. Serum samples were analyzed for urea nitrogen concentration using the Roche® Reagent for PUN (Roche Diagonic Systems, Somerville) and a COBAS FARA II clinical analyzer (Roche Diagonic Systems, Branchburg, NJ.).

In both experiments, performance data were analyzed according to a randomized complete block design (Steel and Torrie, 1980) with pen as the experimental unit and blocks based on initial body weight. Analysis of variance was performed using the

general linear model (GLM) procedures of SAS (1988), and orthogonal polynomials were used to test for linear, quadratic, and cubic effects. Plasma urea nitrogen (PUN) data were analyzed by split-plot analysis of variance with treatment as the main plot and sampling day as the sub plot and all appropriate interactions.

RESULTS

Experiment 1

The results from chemical amino acid analysis of the four experimental diets fed from day 0 to 14 in Experiment 1 are shown in Table 3.3. The effect of increasing lysine level in the diets on average daily gain (ADG), average daily feed intake (ADFI), and gain:feed (G:F) during Experiment 1 is shown in Table 3.4. The effect of increasing lysine level in the diets on ADG and G:F during Phase 1 (d 0 to 14 postweaning) in Experiment 1 is also shown in Figure 3.1. In Experiment 1, from day 0 to 7 and 0 to 14 postweaning (Phase 1), ADG and G:F were improved linearly ($P < .01$) as dietary lysine increased, with ADG maximized at 1.75% dietary lysine. Pigs fed 1.75% dietary lysine with addition of WPC as the lysine source grew 41% and 18% faster and gained 33% and 30% more per kg of feed than pigs fed 1.30% dietary lysine without addition of WPC during day 0 to 7 and 0 to 14 postweaning, respectively. However, ADFI was not significantly affected ($P>.10$) by dietary lysine level.

From day 7 to 14 postweaning, ADG of pigs fed 1.75% dietary lysine was not significantly affected ($P<.10$) by dietary lysine level. However, G:F improved linearly ($P<.01$) as dietary lysine increased with the greatest increase at 1.75% dietary lysine.

Pigs fed 1.75% dietary lysine with addition of WPC as the lysine source gained 25% more per kg of feed than pigs fed 1.30% dietary lysine without addition of WPC. Average daily feed intake (ADFI) decreased linearly (P<.01) as dietary lysine increased with the greatest increase at 1.30% dietary lysine. Pigs fed 1.75% dietary lysine with addition of WPC as the lysine source consumed 15% less feed than pigs fed 1.30% dietary lysine without addition of WPC.

Diets fed from day 14 to 28 and 28 to 42 postweaning had no effect (P>.10) on growth performance. During the overall 42-d experimental period (from day 0 to 42 postweaning), a linear increase (P<.01) in G:F was observed with increasing dietary lysine level with the greatest G:F at 1.75% dietary lysine from day 0 to 14 postweaning (Phase 1). However, ADG and ADFI were not significantly affected (P > .10) by dietary lysine level during the same period. During the overall 42-d experimental period, pigs initially fed 1.75% dietary lysine with addition of WPC as the lysine source during Phase 1 gained 9% more per kg of feed than pigs initially fed 1.30% dietary lysine without WPC in the same period.

Experiment 2

The results from chemical amino acid analysis of the five experimental diets fed from day 0 to 14 in Experiment 2 are shown in Table 3.7. The effect of increasing lysine level in the diets on ADG, ADFI, and G:F during Experiment 2 is shown in Table 3.8. The effect of increasing lysine level in the diets on ADG, ADFI, and G:F during Phase 1 in Experiment 2 is also shown in Figure 3.2 and 3.3. In Experiment 2, from day 0 to 7, 7 to 14, and 0 to 14 postweaning, ADG and G:F increased linearly (P < .006) as dietary

lysine level increased with the greatest increase at 1.90% dietary lysine. Pigs fed 1.90% dietary lysine with addition of WPC as the lysine source grew 44%, 39%, and 41% faster and gained 37%, 35%, and 36% more per kg of feed than pigs fed 1.30% dietary lysine without WPC during day 0 to 7, 7 to 14, and 0 to 14 postweaning, respectively. However, ADFI was not significantly affected ($P > .10$) by dietary lysine levels.

Diets fed from day 14 to 28 and 28 to 42 postweaning had no effect ($P>.10$) on growth performance. During the overall 42-day experimental period, a linear increase ($P < .006$) in ADG and G:F was observed with increasing dietary lysine in the diet. Pigs initially fed 1.90% dietary lysine with addition of WPC as the lysine source during Phase 1 had 16% greater gains and G:F than those initially fed 1.30% dietary lysine without addition of WPC during the same period. However, ADFI was not significantly affected ($P>.10$) by dietary lysine levels.

Plasma urea nitrogen (PUN) concentrations on day 14, 28, and 42 of the experiment were varied and were not affected ($P>.10$) by dietary lysine levels (Table 3.8). However, the average total plasma urea nitrogen concentrations for each day increased linearly ($P<.01$) as dietary lysine level increased with the greatest level at 1.90% dietary lysine with addition of WPC (Table 3.8 and Figure 3.3). In addition, the average total PUN concentrations for each collection day of pigs fed dietary lysine with addition of WPC as the lysine source tended to be greater than those of pigs fed dietary lysine without addition of WPC.

DISCUSSION

Research estimating the lysine requirement in segregated early-weaned pigs is limited. The NRC (1988) recommends the lysine requirement of 1 to 5 kg, 5 to 10 kg, and 10 to 20 kg pigs (allowed feed ad libitum, 90% dry matter) as 1.40%, 1.15%, and .95%, respectively. In addition, more recently the NRC (1998) estimated that the lysine requirement of 3 to 5 kg, 5 to 10 kg and 10 to 20 kg pigs (allowed feed ad libitum, 90% dry matter) as 1.50%, 1.35%, and 1.15%, respectively. However, in our studies, ADG and gain:feed for pigs during day 0 to 7 and 0 to 14 postweaning were maximized in pigs fed 1.75% lysine for Experiment 1 and 1.90% lysine for Experiment 2. This finding is consistent with the work of Owen et al. (1994), who reported that ADG from day 0 to 7 postweaning was maximized in pigs fed between 1.65 and 1.80% dietary lysine with the highest G:F for SEW pigs fed 1.80% lysine and average daily gain (ADG) and gain:feed (G:F) from day 0 to 14 postweaning improved by increasing dietary lysine with the greatest increase at approximately 1.65% dietary lysine. Thus, the present results from our studies suggest that the NRC (1988 or 1998) recommendation may have underestimated the lysine requirement for young pigs. This interpretation agrees with the work of Stahly et al. (1994), who reported that feed efficiency was optimized by dietary lysine levels of 1.80% for high lean growth strains and suggested that segregated early-weaned pigs need much higher lysine requirements than levels recommended by NRC (1988 or 1998).

Since whey has a relatively high digestibility (Lepine et al., 1991) and provides a high nutritive value due to its relatively complete amino acid profile (Smith, 1976), it has

been recognized as a suitable source of nutrients for diets of young pigs. In addition, WPC can serve as an excellent protein (amino acids) or lysine source in young pig diets to improve growth performance. A study by Cieslak et al. (1986), who compared WPC with soybean meal as a protein source to maize for growing pigs, reported that growth rate per unit of crude protein was higher if 50% of dietary protein was supplied by WPC (35% CP). Cinq-Mars et al. (1986) reported that early-weaned pigs (weaned at 3 to 4 wk of age) fed corn-soybean-fish meal-based diet with addition of liquid WPC as a source of protein and energy grew faster and gained more per kg of feed than those fed corn-soybean-fishmeal based diet without addition of liquid WPC. In our studies, increasing dietary lysine level by supplementation of WPC (77% CP) as the lysine source resulted in enhanced ADG and G:F during the first two weeks postweaning and the entire 42-d experiment. In addition, pigs fed diets with addition of WPC as a lysine source showed greater ADG and G:F than pigs fed diets without addition of WPC. These results are in agreement with the work of Davis et al. (1996a, 1996b), who reported that ADG and G:F improved with increasing dietary lysine when WPC (77% CP) served as the lysine source during Phase 1 (from day 0 to 14) of the nursery period. Pigs fed the dietary lysine with supplementation of WPC as the lysine source had greater ADG and G:F than pigs fed the dietary lysine without supplementation of WPC.

There have been many attempts to identify the reasons why early-weaned pigs have improved performance when dried whey is added as an ingredient in starter rations. Some experiments indicate that nutrient factors other than lysine in dried whey enhance postweaning growth performance of early weaning pigs. Mahan et al. (1993) reported that in weanling pigs, lysine was not a limiting factor in either a corn-soybean meal or

corn-soybean meal-dried whey diet formulated to either .95% or 1.10%, and another factor in dried whey was assumed to be responsible for its growth promotion effect. Tokach et al. (1989) reported that both the carbohydrate (lactose) and protein (lactalbumin) fractions of dried whey were important factors that improved growth performance of early weaned pigs when dried whey was fed. However, Mahan (1992) suggested that the lactose not the lactalbumin component of dried whey is the primary factor that stimulated growth performance of young pigs. In addition, Lepine et al. (1991) suggested that a component of dried whey other than lysine (e.g., lactose) was the most limiting nutrient in corn-soybean meal-based diets, but when dried whey was supplemented, growth responses to crystalline lysine occurred during the latter phase of the starter period. These authors suggested also that a highly available carbohydrate source such as lactose might be necessary to achieve maximum growth responses in weanling pigs fed a corn-soybean meal diet supplemented with L-Lysine·HCl.

Plasma urea nitrogen (PUN) concentration has been used as an indicator of amino acid utilization. Plasma urea nitrogen concentration increases when there is an amino acid imbalance in the diet. If an amino acid is limiting or at deficient levels, it restricts the utilization of other non-limiting or sufficient levels of amino acids for protein synthesis. Then, these surplus amino acids are utilized for urea synthesis resulting in increased PUN concentration. On the other hand, PUN concentrations of pigs tended to be increased when the dietary amino acid concentrations greater than the requirement were fed (Lewis et al., 1977, 1981; Coma et al., 1995). This observation is presumably caused by the fact that feeding dietary amino acid concentrations greater than the

requirement results in an excess of amino acids that are catabolized and thus, the enhanced urea synthesis rate results in greater PUN concentrations (Coma et al., 1995).

In our studies, the average total PUN concentration for each collection day of pigs fed dietary lysine with addition of WPC as the lysine source tended to be greater than those of pigs fed dietary lysine without addition of WPC. This effect probably resulted from the increased WPC addition as the lysine source in diets to attain the higher lysine levels which caused many excesses of amino acids that were converted to urea nitrogen. Concentrations of plasma urea nitrogen were increased (linearly, $P<.01$) with increasing dietary lysine in the diet (Table 3.8). This observation is in agreement with the result reported by Owen et al. (1995), who found that plasma urea nitrogen increased with increasing dietary lysine from 1.40% to 1.80%.

IMPLICATIONS

The results of the present study suggest that segregated early-weaned pigs require at least 1.75% of total lysine to optimize growth performance during day 0 to 14 postweaning when whey protein concentrate serves as the dietary lysine source. In addition, pigs fed diets with addition of WPC as a lysine source had greater ADG and G:F than pigs fed a control diet without addition of WPC. The results from the present study suggest that the NRC (1988 or 1998) recommendation for the lysine requirement of early-weaned pigs is too low and WPC can be an excellent protein or lysine source in the diets for segregated early-weaned pigs to improve growth performance.

Table 3.1. Composition of experimental diets (Exp. 1)[a].

	Diet					
	SEW diets, lysine %				Transition	Phase 2
Ingredient, %	1.30	1.45	1.60	1.75	Diet	Diet
Corn, ground	28.37	28.37	28.37	28.37	48.79	55.08
Lactose	13.56	13.10	12.65	12.20	-	10.00
Whey	12.00	12.00	12.00	12.00	20.00	-
Soybean meal, 48%	-	-	-	-	12.75	22.25
Steam-rolled oats	10.00	10.00	10.00	10.00	-	-
Fish meal	8.00	8.00	8.00	8.00	8.00	5.00
WPC, 77%[b]	-	3.20	6.40	9.61	-	-
Corn starch	4.00	2.68	1.33	-	-	-
Sucrose	3.99	2.67	1.32	-	-	-
Dried skim milk	5.00	5.00	5.00	5.00	-	-
AP-300[c]	-	-	-	-	1.50	2.00
AP-920[d]	5.00	5.00	5.00	5.00	2.50	-
Egg protein	4.00	4.00	4.00	4.00	-	-
Soy oil	3.00	3.00	3.00	3.00	4.00	2.50
Calcium carbonate	-	-	-	-	0.15	0.27
Dical	1.07	1.00	0.95	0.85	0.60	1.43
Lysine·HCl	0.10	0.10	0.10	0.10	-	0.15
Threonine	0.01	-	-	-	-	0.05
Methionine	0.09	0.07	0.07	0.06	0.10	0.12
Neoterramycin[e]	1.00	1.00	1.00	1.00	1.00	-
Ethoxyquin	0.03	0.03	0.03	0.03	0.03	0.03
Flavor	0.10	0.10	0.10	0.10	-	-
Salt	-	-	-	-	0.20	0.30
Tylan40-Sulfa[f]	-	-	-	-	-	0.13
$CuSO_4$	-	-	-	-	-	0.05
Zinc oxide	0.30	0.30	0.30	0.30	-	0.30
Micro curb	-	-	-	-	-	0.10
Vit. TM premix[g]	0.38	0.38	0.38	0.38	0.38	0.25
Biotin supplement	0.001	0.001	0.001	0.001	-	-

[a] As fed basis. Diets were formulated to contain .90% Ca, and .79% P in SEW phase; 1.40% lysine, .85% Ca, and .75% P in transition phase; 1.35% lysine, .80% Ca, and .70% P in Phase 2, and to exceed the NRC (1988) standards for all nutrients.

[b] Whey protein concentrate, 77% CP.

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

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

[e] Contained 10 g of neomycin and 5 g of oxytetracycline per kg.

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

[g] Vitamins and minerals met or exceeded the NRC (1988) requirements.

Table 3.2. Calculated composition of crude protein, lactose, amino acids, calcium, and phosphorus in diets containing whey protein concentrate as an amino acid source (Exp. 1).

	SEW Diets			
	Lysine, %			
Calculated composition, %	1.30	1.45	1.60	1.75
Crude Protein , total	18.06	20.50	22.96	25.40
Lysine	1.30	1.45	1.60	1.75
Tryptophan	.23	.29	.34	.39
Threonine	.84	.95	1.08	1.21
Met. + Cys.	.78	.86	.96	1.04
Valine	1.04	1.17	1.30	1.42
Isoleucine	.79	.92	1.05	1.17
Phenylalanine	.85	.95	1.04	1.14
Tyrosine	.65	.75	.85	.94
Leucine	1.61	1.77	1.92	2.08
Arginine	.94	1.00	1.05	1.10
Histidine	.45	.50	.56	.61
Ca	.90	.90	.90	.90
P	.79	.79	.79	.79
Lactose	24.01	24.01	24.01	24.01

Table 3.3. Chemical amino acid analysis of experimental diets fed during Phase 1 (Exp.1)[a].

	SEW Diets			
	Lysine, %			
Amino Acids	1.30	1.45	1.60	1.75
Crude Protein , total	17.61	20.90	23.84	25.11
Lysine	1.14	1.47	1.71	1.92
Tryptophan	.24	.31	.39	.44
Threonine	.75	.91	1.06	1.20
Methionine	.41	.49	.57	.59
Cysteine	.35	.46	.51	.58
Valine	.91	1.12	1.25	1.34
Isoleucine	.69	.89	1.02	1.12
Phenylalanine	.79	.92	1.02	1.11
Tyrosine	.54	.63	.73	.85
Leucine	1.54	1.92	2.25	2.55
Arginine	.93	1.01	1.09	1.17
Histidine	.44	.51	.57	.61
Glycine	.77	.85	.92	.95
Proline	1.01	1.14	1.27	1.40
Alanine	.96	1.11	1.26	1.37
Glutamic acid	2.71	3.22	3.60	4.11
Serine	.73	.83	.95	1.07
Aspartic acid	1.47	1.79	2.09	2.35
Ornithine	.01	.01	.01	-
Taurine	.06	.30	.06	.28
Hydroxyproline	.08	.08	.09	.08
Hydroxylysine	-	.01	.02	.02
Lanthionine	-	-	-	-

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

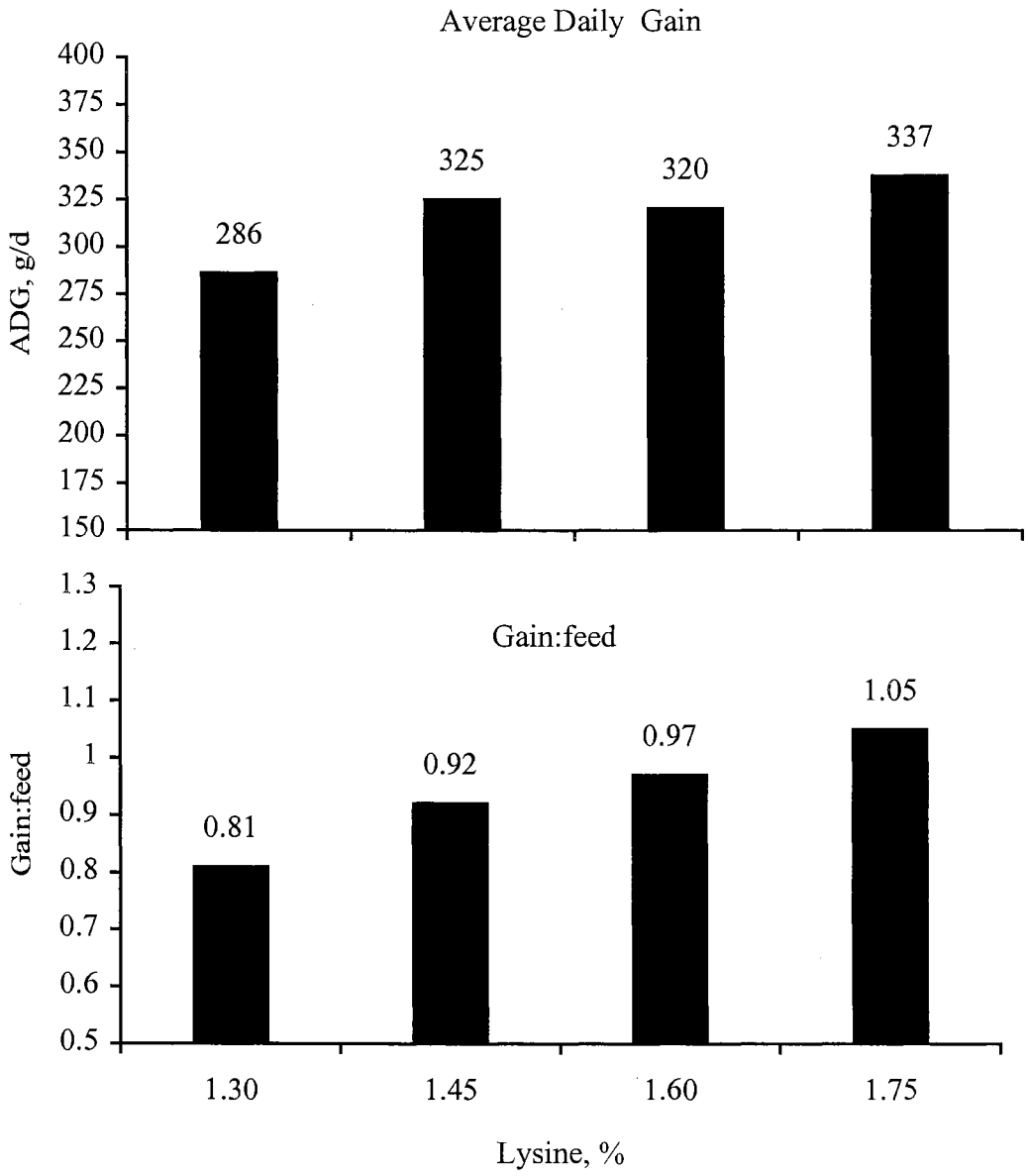

Figure 3.1. Average daily gain (Top panel) and gain:feed (Bottom panel) of pigs fed the four dietary treatments during Phase 1 (from d 0 to 14 postweaning)- Exp. 1.

Table 3.4 Performance of pigs (12 to 16 days of age) fed increasing levels of dietary lysine (Exp. 1)[a].

	Lysine, %				
Item	1.30	1.45	1.60	1.75	SEM
Day 0 to 7					
ADG, g[b]	162	199	212	229	15.25
ADFI, g	197	211	211	211	211
Gain:feed[b]	.83	.94	.99	1.10	.031
Day 7 to 14					
ADG, g	409	452	428	446	10.18
ADFI, g[b]	516	501	455	449	14.13
Gain:feed[b]	.80	.90	.95	.99	.013
Day 0 to 14					
ADG, g[b]	286	325	320	337	10.36
ADFI, g	356	356	333	330	12.94
Gain:feed[b]	.81	.92	.97	1.05	.016
Day 14 to 28					
ADG, g	536	509	534	501	13.29
ADFI, g	732	696	750	717	12.48
Gain:feed	.73	.73	.71	.70	.017
Day 28 to 42					
ADG, g	700	691	710	709	14.04
ADFI, g	994	988	1082	1020	28.00
Gain:feed	.71	.70	.66	.70	.013
Day 0 to 42					
ADG, g	507	508	521	516	7.99
ADFI, g	694	680	722	689	12.95
Gain:feed[b]	.75	.78	.78	.82	.008

[a] Data are means of 5 pens of 3 pigs each. Pigs averaged 4.2 kg and 25.9 kg at initiation and termination, respectively.

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

Table 3.5. Composition of experimental diets (Exp. 2)[a].

	SEW diet				
	Lysine, %				
Ingredient, %	1.30	1.45	1.60	1.75	1.90
Corn, ground	23.00	23.00	23.00	23.00	23.00
Lactose	6.81	6.35	5.90	5.45	5.02
Whey	21.96	21.96	21.96	21.96	21.96
Steam-rolled oats	10.00	10.00	10.00	10.00	10.00
Fish meal	8.00	8.00	8.00	8.00	8.00
Whey prot. Conc.,77%	-	3.19	6.38	9.57	12.60
Corn starch	5.27	3.93	2.60	1.26	-
Sucrose	5.26	3.92	2.59	1.26	-
Dried skim milk	5.00	5.00	5.00	5.00	5.00
AP-920[b]	5.00	5.00	5.00	5.00	5.00
Egg protein	4.00	4.00	4.00	4.00	4.00
Soy oil	3.00	3.00	3.00	3.00	3.00
Calcium carbonate	.02	-	-	-	-
Dical	.80	.77	.71	.64	.57
Methionine	.07	.07	.05	.05	.04
Neoterramycin[c]	1.00	1.00	1.00	1.00	1.00
Ethoxyquin	.03	.03	.03	.03	.03
Flavor	.10	.10	.10	0.10	.10
Zinc oxide	.30	.30	.30	.30	.30
Vit. TM premix[d]	.38	.38	.38	.38	.38
Biotin supplement	.001	.001	.001	.001	.001

[a] As fed basis. Diets were formulated to contain .92% Ca, and .80% P in SEW phase; 1.40% lysine, .85% Ca, and .75% P in transition phase; 1.35% lysine, .80% Ca, and .70% P in Phase 2, and to exceed the NRC (1988) standards for all nutrients.

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

[c] Contained 10 g of neomycin and 5 g of oxytetracycline per kg.

[d] Vitamins and minerals met or exceed the NRC (1988) requirements.

Table 3.6. Calculated compositions of crude protein, lactose, amino acids, calcium, and phosphorus in diets containing whey protein concentrate as an amino acid source (Exp. 2).

	SEW diet				
	Lysine, %				
Calculated composition, %	1.30	1.45	1.60	1.75	1.90
Crude protein	18.82	21.28	23.71	26.17	28.49
Lysine	1.30	1.45	1.60	1.75	1.90
Tryptophan	.24	.30	.35	.40	.45
Threonine	.89	1.01	1.14	1.27	1.39
Met. + Cys.	.78	.88	.96	1.06	1.14
Valine	1.08	1.21	1.34	1.47	1.59
Isoleucine	.85	.98	1.11	1.24	1.36
Phenylalanine	.86	.96	1.05	1.15	1.24
Tyrosine	.66	.76	.86	.95	1.04
Leucine	1.67	1.82	1.98	2.14	2.29
Arginine	.96	1.01	1.06	1.11	1.16
Histidine	.45	.51	.56	.61	.67
Ca	.92	.92	.92	.92	.92
P	.80	.80	.80	.80	.80
Lactose	24.00	24.00	24.00	24.00	24.00

Table 3.7. Chemical amino acid analysis of experimental diets fed during Phase 1 (Exp. 2)[a].

	SEW diet				
	Lysine, %				
Amino acids	1.30	1.45	1.60	1.75	1.90
Crude Protein , total	18.89	21.82	23.68	26.48	28.40
Lysine	1.18	1.44	1.65	1.83	2.02
Tryptophan	.29	.34	.41	.46	.51
Threonine	.86	1.01	1.13	1.28	1.37
Methionine	.44	.58	.54	.60	.62
Cysteine	.38	.54	.52	.59	.64
Valine	.93	1.12	1.28	1.35	1.40
Isoleucine	.73	.91	1.07	1.13	1.18
Phenylalanine	.82	.93	1.08	1.11	1.17
Tyrosine	.59	.67	.76	.85	.91
Leucine	1.64	2.00	2.32	2.61	2.79
Arginine	.91	1.00	1.08	1.14	1.20
Histidine	.45	.52	.57	.61	.65
Glycine	.78	.84	.91	.96	.99
Proline	1.06	1.18	1.31	1.41	1.49
Alanine	1.00	1.14	1.27	1.41	1.48
Glutamic acid	2.80	3.26	3.71	4.13	4.41
Serine	.79	.90	.97	1.10	1.18
Aspartic acid	1.60	1.90	2.19	2.45	2.63
Ornithine	.01	.01	.01	.01	.01
Taurine	.32	.30	.29	.06	.27
Hydroxyproline	.07	.07	.08	.08	.07
Hydroxylysine	-	.01	.02	.02	.02
Lanthionine	-	-	-	-	-

[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.

Table 3.8. Performance of pigs (12 to 16 days of age) fed increasing levels of dietary lysine (Exp. 2)[a].

	Lysine, %					
Item	1.30	1.45	1.60	1.75	1.90	SEM
Day 0 to 7						
ADG, g[b]	184	193	239	266	266	16.70
ADFI, g	200	206	209	227	214	12.36
Gain:feed[b]	.92	.94	1.16	1.18	1.26	.047
Day 7 to 14						
ADG, g[b]	334	403	461	446	465	24.22
ADFI, g	430	471	511	464	446	25.09
Gain:feed[b]	.78	.86	.90	.97	1.05	.020
Day 0 to 14						
ADG, g[b]	259	298	350	356	365	18.33
ADFI, g	315	339	360	345	330	17.09
Gain:feed[b]	.85	.90	1.03	1.07	1.16	.028
Day 14 to 28						
ADG, g	471	450	483	519	507	25.88
ADFI, g	633	645	649	674	669	29.96
Gain:feed	.74	.70	.74	.77	.76	.017
Day 28 to 42						
ADG, g	634	676	681	676	706	25.05
ADFI, g	906	943	947	999	994	40.04
Gain:feed	.70	.72	.72	.68	.72	.022
Day 0 to 42						
ADG, g[b]	455	475	504	517	526	17.70
ADFI, g	618	642	652	673	665	24.69
Gain:feed[b]	.76	.77	.83	.84	.88	.012
Plasma Urea N, mg/dL						
Day 14	7.34	6.89	10.24	10.95	10.37	.89
Day 28	6.42	7.01	6.51	7.10	7.66	.92
Day 42	7.09	7.37	8.10	8.93	9.00	1.05
Overall[b]	6.95	7.09	8.29	8.99	9.01	.62

[a] Data are means of 4 pens of 4 pigs each. Pigs averaged 4.5 kg and 25.3 kg at initiation and termination, respectively.

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

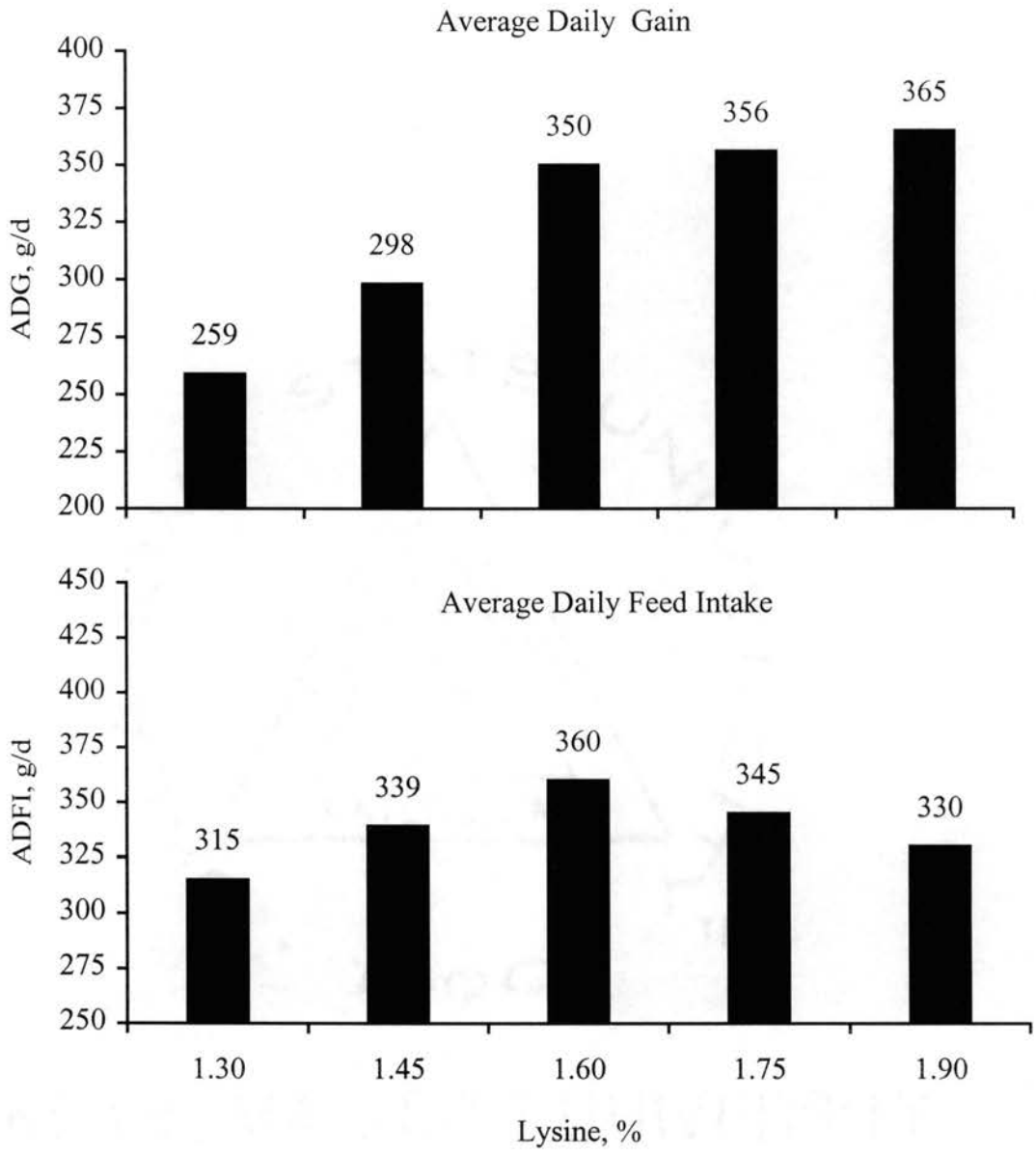

Figure 3.2. Average daily gain (Top panel) and average daily feed intake (Bottom panel) of pigs fed the five dietary treatments during Phase 1 (from d 0 to 14 postweaning)-Exp. 2.

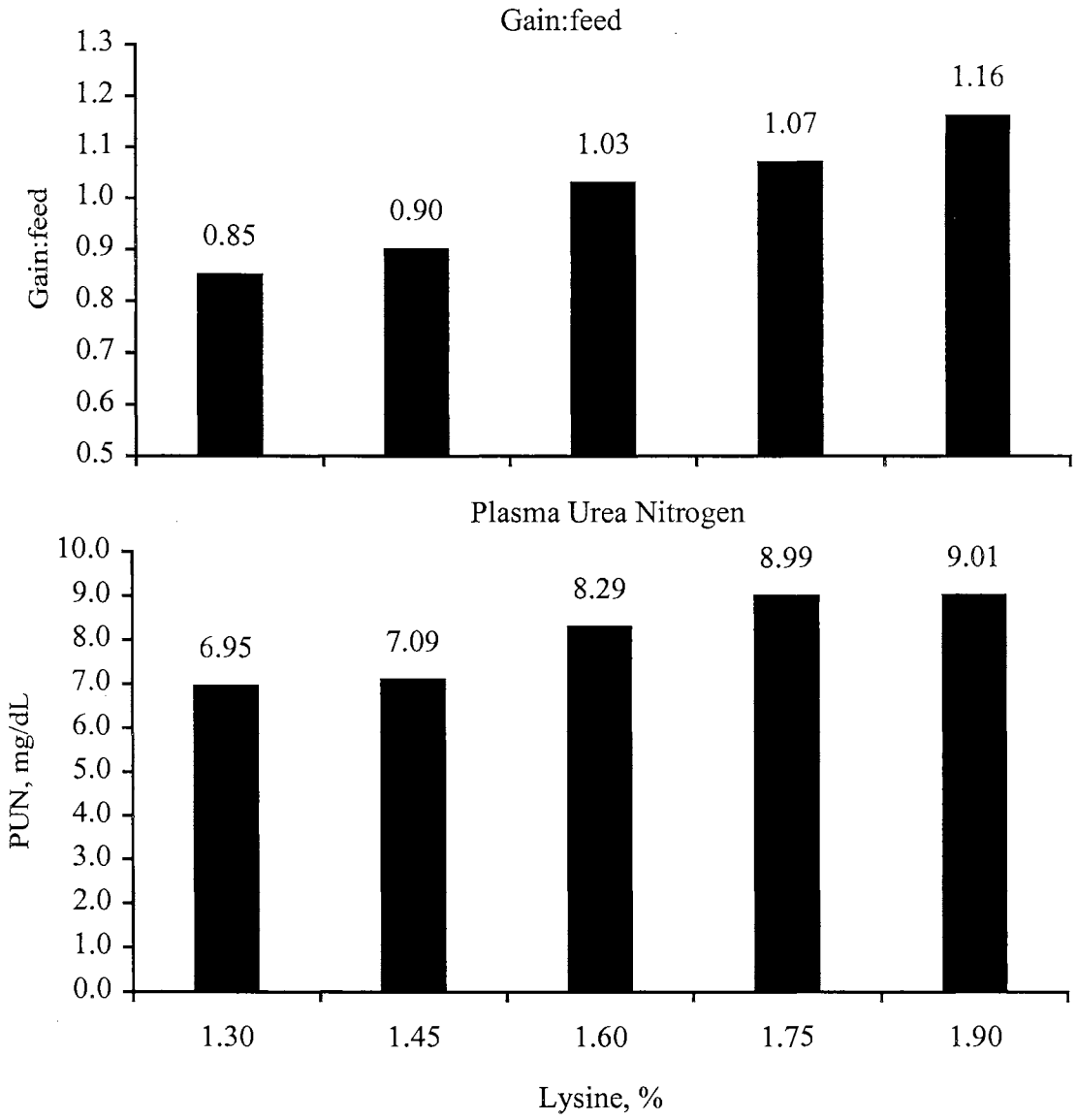

Figure 3.3. Gain:feed (Top panel) of pigs fed the five dietary treatments during Phase 1 (from d 0 to 14 postweaning) and the average total plasma urea nitrogen concentrations (Bottom panel) of pigs fed the five dietary treatments that were collected on d 14, 28, and 42 of the experiment-Exp. 2.

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CHAPTER IV

HIGH QUALITY PROTEIN VS CRYSTALLINE AMINO ACIDS AS AN AMINO ACID SOURCE FOR SEGREGATED EARLY-WEANED PIGS

ABSTRACT

A total of 80 pigs (14±2 days of age and 4.7 kg average initial BW) were used to evaluate the efficacy of whey protein concentrate (WPC, 77%) or a mixture of crystalline amino acids (CAA) at two lysine (Lys) concentrations on growth performance and plasma urea nitrogen (PUN) of segregated early-weaned (SEW) pigs. Pigs were housed in an off-site nursery with four pigs per pen and four pens per treatment and were assigned to five dietary treatments arranged as a 2x2 factorial with a negative control (NC, 1.12% digestible Lys and no WPC). The factorially arranged treatments consisted of two Lys levels (1.40% and 1.68% digestible Lys) with WPC as a natural intact source of amino acids or the WPC component replaced by an ideal mixture of CAA. Experimental diets contained corn, lactose, dried whey (21.96%), steam-rolled oats (10.0%), fish meal (8.0%), dried skim milk (5.0%), spray-dried plasma protein (5.0%), egg protein (4.0%), and soy oil (3.0%). Cornstarch and sucrose were replaced by WPC or CAA to increase Lys concentrations in each experimental diet. Calculated composition of lactose in all diets was 24%. Experimental diets were fed from d 0 to 14 postweaning

(Phase 1), then all pigs were fed a common transition (1.40% Lys) and a Phase 2 (1.35% Lys) diets. From d 0 to 7 and d 7 to 14 postweaning, pigs fed NC had lower (P<.01) ADG and G:F than those fed WPC. In the same period, pigs fed NC had lower (P<.01) G:F than those fed CAA. From d 0 to 14 postweaning, pigs fed NC had lower (P<.01) ADG and G:F than those fed WPC or lower ADG and G:F (P<.09 and P<.01, respectively) than those fed CAA. Pigs fed WPC grew faster (P<.05) than pigs fed CAA. Gain:feed (G:F) increased with increasing Lys level in the WPC diets and decreased with increasing Lys level in the CAA diets (Lys source x Lys level interaction, P<.05). For the entire 42-day experiment, pigs previously fed WPC during the first two weeks grew faster (P<.05) and were more efficient (P<.01) than pigs previously fed NC during first two weeks. In addition, pigs previously fed WPC during first two weeks were more efficient (P<.05) than pigs previously fed CAA during first two weeks. Pigs fed the NC diet had lower (P<.01) PUN concentrations than those fed the WPC diets and higher (P<.01) PUN concentrations than those fed the CAA diets. There was an increase in PUN concentrations (on d 14) with increasing Lys levels in the WPC diets, but a decrease in PUN concentrations with increasing Lys levels in the CAA diets (Lys source x Lys level interaction, P<.05). These data indicate that adding CAA to the diet of SEW pigs improved performance when compared with pigs fed a low-protein negative control diet, but did not produce equivalent performance when compared with pigs fed WPC.

INTRODUCTION

Previous research (Experiment 1 and 2: Chapter III) at Oklahoma State University to determine the lysine requirement of segregated early-weaned (SEW) pigs fed a high-nutrient dense diet with whey protein concentrate (WPC) as the supplemental source of natural intact amino acids resulted in a linear increase in growth performance with increasing lysine level (1.30, 1.45, 1.60, 1.75, and 1.90 Lys). However, the question remains whether this improvement in performance was due to the lysine concentration of WPC or was due to component(s) other than lysine present in WPC. Cinq-Mars et al. (1986) reported that the inclusion of whey protein up to 33.7% (of the dry matter) in corn-soybean meal-based diets for early-weaned pigs (3 to 4 weeks of age) resulted in improved gain and efficiency of gain. Tokach et al. (1989) reported that both carbohydrate (lactose) and protein (lactalbumin) component of dried whey were important factors that enhance growth performance of early-weaned pigs when dried whey was fed. Moreover, Mahan (1992) indicated that the inclusion of high-quality dried whey in the diet of weanling pigs resulted in improved performance and suggested that the lactose component of dried whey, not lactalbumin was the primary component that improved postweaning performance. Therefore, the objective of this study was to evaluate the efficacy of WPC and a mixture of crystalline amino acids (CAA) at two lysine levels on performance and plasma urea nitrogen (PUN) of SEW pigs.

MATERIALS AND METHODS

A total of 80 weanling pigs (Yorkshire, Hampshire, and Yorkshire x Hampshire) averaging 4.7 kg BW and 14±2 days of age was used in a 42-d growth assay to evaluate the efficacy of WPC and a mixture of crystalline amino acids (CAA) at two lysine levels on pig performance. At weaning, pigs were sorted by weight, and divided into four weight groups (blocks). Weight groups contained 20 pigs each. Pigs within each weight group were allotted into five equal subgroups (four pigs per pen) with stratification based on sex and litter. The pens within each of the four weight groups were randomly assigned to five dietary treatments (four pens per treatment). Treatments were assigned as a 2 x 2 factorial with a negative control (NC). The negative control was formulated to contain 1.12% digestible lysine and no whey protein concentrate. The factorially arranged treatments consisted of two dietary lysine levels (1.40% and 1.68% digestible lysine) with WPC as a source of natural intact amino acids or the WPC component replaced by an ideal mixture of CAA (Chung and Baker, 1992).

All five experimental diets were fed from day 0 to 14 postweaning (Phase 1) and, contained corn, lactose, 21.96% dehydrated whey, 10% steam-rolled oats, 8% select menhaden fish meal, 5% dried skim milk, 5% spray-dried plasma protein, 4% egg protein, and 3% soy oil (Table 4.1). The lysine levels were achieved by increasing the amount of whey protein concentrate or crystalline amino acids at the expense of cornstarch and sucrose. Calculated composition of lactose in all diets was 24%. All pigs were fed a common transition diet (1.40% total lysine; Table 4.2) from day 14 to 28

postweaning (Transition) and a common Phase 2 diet (1.35% total lysine, Table 4.2) from day 28 to 42 postweaning (Phase 2). All diets met or exceeded National Research Council (NRC, 1988) guidelines. Diets were pelletted with a 100-horsepower pellet mill (California Pellet Mill, San Francisco, CA) equipped with a 3.97-mm die. A representative sample of each diet was collected and analyzed for amino acids according to the AOAC (1984) methods at the Experiment Station Chemical Laboratories at the University of Missouri. Briefly, samples were acid hydrolyzed with degassed 4.2N NaOH, for 4 h at 145°C. For sulfur amino acids, samples were pre-oxidized with performic acid. A Beckman 6300 amino acid analyzer (integrated HPLC system) with a cation exchange resin derivatization with ninhydrin was used to quantify the amino acids in the samples. Amino acid analyses were done singly, and a standard was included with samples. The results of amino acid analysis in the complete diets are shown in Table 4.3.

Pigs were housed in an environmentally-controlled off-site nursery in pens (1.09 m x 1.52 m) with woven wire flooring. The initial ambient temperature was 31°C was subsequently decreased 1°C per week. Pigs in each pen had ad libitum access to one nipple waterer and a three-hole feeder. Pig body weight and feed intake were determined weekly to evaluate average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (G:F). Blood samples were taken via anterior vena cava puncture on day 14 of the trial. Samples were centrifuged, and serum was harvested and stored at -20°C until it was assayed. Serum samples were analyzed for urea nitrogen concentration (PUN) using the Roche® Reagent for PUN (Roche Diagonic Systems, Somerville) and a COBAS FARA II clinical analyzer (Roche Diagonic Systems, Branchburg, NJ.).

Data were analyzed as a randomized complete block design (Steel and Torrie, 1980) with pen as the experimental unit and blocks based on initial body weight. Analysis of variance was performed using the general lineal model (GLM) of SAS (1988). A comparison of the negative control versus the average of the diets containing WPC and the negative control versus the average of the diets containing a mixture of CAA were made. Also, the effects of lysine source, lysine level, and the lysine source x lysine level interaction were evaluated by using orthogonal contrast.

RESULTS

The effects of lysine source and level on performance and plasma urea nitrogen concentration during the experiment are shown in Table 4.4. From day 0 to 7 postweaning, pigs fed the negative control (NC) diet had lower ($P<.01$) average daily gain (ADG) and gain:feed (G:F) than those fed the WPC diets. Pigs fed the CAA diets had lower ($P<.07$) ADG than those fed the WPC diet. Gain:feed (G:F) was greater ($P<.01$) for pigs fed the CAA diets than for those fed the NC diet. The response to amino acid supplementation from the two sources (WPC or CAA) resulted in a lysine source x lysine level interaction ($P<.09$). Average daily feed intake (ADFI) was not significantly affected ($P>.10$) by the level and source of dietary supplemental amino acid.

From day 7 to 14 postweaning, pigs fed the NC diet had lower ($P<.01$) ADG and G:F than the average of pigs receiving the WPC diets. Pigs fed the CAA diets had lower ADG and G:F ($P<.08$ and $P<.10$, respectively) than those fed the WPC diets. Pigs fed the NC diet had lower ($P<.01$) G:F than those fed the CAA diets. However, ADFI was not

significantly affected (P>.10) by the level and source of dietary supplemental amino acid. In addition, the effect of lysine source, lysine level, and the lysine source x lysine level interaction were not significantly detected (P>.10) among dietary treatments.

The effects of lysine source and level on performance during Phase 1 (from day 0 to 14 postweaning) are shown in Figure 4.1 and 4.2. From day 0 to 14 postweaning, pigs fed the NC diet had lower (P<.01) ADG and G:F than those fed the WPC diets, and lower ADG and G:F (P<.09 and P<.01, respectively) than pigs fed the CAA diets. Pigs given the diets containing WPC had greater gains (P<.05) than those consuming the diets containing CAA. Gain:feed (G:F) increased with increasing lysine level in the WPC diets, but decreased with increasing lysine level in the CAA diets (Lysine source x lysine level interaction, P<.05; Figure 4.2). However, ADFI was not significantly affected (P>.10) by the level and source of dietary supplemental amino acid.

From day 14 to 28 (Transition), performance was similar among pigs previously fed the varying levels of dietary protein and lysine. Average daily gain (ADG), ADFI, and G:F were not significantly affected (P>.10) by dietary treatments. From day 28 to 42 (Phase 2), ADG of pigs previously fed 1.40% digestible lysine during first two weeks was greater (P<.06) than for pigs previously fed 1.68% digestible lysine in the same period. However, ADFI and G:F were not significantly affected (P>.10) by dietary treatments.

For the entire 42-day experiment ADG and G:F of pigs fed diets containing WPC during the initial two weeks of the study were greater (P<.05 and P<.01, respectively) than for pigs fed the negative control diet in the same period. Pigs fed the WPC diets had

greater (P<.05) G:F than pigs fed the CAA diets. However, ADFI was not significantly affected (P>.10) by the level and source of dietary supplemental amino acid.

The effects of lysine source and level on PUN concentration collected on day 14 of the experiment are shown in Figure 4.2. Pigs fed the NC diet had lower (P<.01) PUN concentration than those fed the WPC diets and higher (P<.01) PUN concentration than the average pigs fed the CAA diets. There was an increase in PUN concentration when lysine levels increased in the WPC diets, but a decrease in PUN concentration when lysine levels increased in the CAA diets (Lysine source x lysine level interaction, P<.05; Figure 4.2).

DISCUSSION

In the present study, the addition of WPC as the natural intact amino acid source to the diet of SEW pigs improved performance when compared with pigs fed a low-protein negative control or pigs fed CAA, irrespective of the level of the amino acid supplementation. Similarly, Fickler et al., (1994) reported a 24% decrease in growth rate of 10-kg pigs fed a chemically defined diet containing essential amino acids as recommended by Chung and Baker (1992) and a complete mixture of nonessential amino acids when compared with pigs fed the control diet containing grains, soybean meal, fish meal and skim milk as the source of amino acids. However, these results are not consistent with the work of Davis (1996a), who reported that ADG and G:F were similar in pigs fed the WPC diet or the CAA diet at the lower level of lysine supplementation (1.22% available lysine) but, at higher level of lysine supplementation (1.43% available

lysine), there was an increased ADG and G:F when WPC was used as the amino acid source and a reduction in ADG and G:F when CAA were used.

In the present study, G:F during the first 14 day postweaning increased with increasing lysine levels in SEW pigs fed WPC-based diets, but decreased with increasing lysine levels in those fed CAA diets. These results are consistent with those of Davis et al. (1997) who reported that in conventionally-weaned pigs, increasing WPC improved ADG and G:F, whereas ADG and G:F decreased with increasing level of crystalline amino acids during the first two weeks postweaning. However, these results are contrary to the findings of Owen et al. (1994) who reported that ADG and feed efficiency of SEW pigs improved during the first two weeks postweaning when L-lysine HCl was used to obtained 1.80% total lysine. Stables and Carr (1976), on the other hand, reported that feed refusals were more common with addition of L-lysine HCl and/or DL-methionine to corn-meat and bone meal diets fed to growing pigs, but this depression in feed intake was alleviated with the addition of tryptophan.

Whey protein concentrate can be utilized as an excellent protein (Cieslak et al., 1986; Cinq-Mars et al., 1986) or lysine (Davis et al., 1996a, 1996b) source in young pig diets to enhance gain and feed response. However, some studies indicate that nutrient factors other than lysine in dried whey improve postweaning growth performance of early weaning pigs. Mahan et al. (1993) reported that in weanling pigs, lysine was not a limiting factor in either a corn-soybean meal or corn-soybean meal-dried whey diet formulated to either .95% or 1.10%, and another factor in dried whey was assumed to be responsible for its growth promotion effect. Tokach et al. (1989) reported that both the carbohydrate (lactose) and protein (lactalbumin) fractions of dried whey were important

factors that improved growth performance of early weaned pigs when dried whey was fed. However, Mahan (1992) suggested that the lactose not the lactalbumin component of dried whey is the primary factor that stimulated growth performance of young pigs. In addition, Lepine et al. (1991) suggested that a component of dried whey other than lysine (e.g., lactose) was the most limiting nutrient in corn-soybean meal based diet, but when dried whey was supplemented, growth responses to crystalline lysine occurred during the latter phase of the starter period. These authors suggested also that a highly available carbohydrate source such as lactose might be necessary to achieve maximum growth responses in weanling pigs fed a corn-soybean meal diet supplemented with L-Lysine·HCl.

Plasma urea nitrogen (PUN) concentration has been used as an indicator of amino acid utilization. Plasma urea nitrogen concentration increases when there is an amino acid imbalance in the diet. If an amino acid is limiting or at deficient levels, it restricts the utilization of other non-limiting or sufficient levels of amino acids for protein synthesis. Then, these surplus amino acids are utilized for urea synthesis resulting in increased PUN concentration. On the other hand, PUN concentrations of pigs tended to be increased when the dietary amino acid concentrations greater than the requirement were fed (Lewis et al., 1977, 1981; Coma et al., 1995). This observation is presumably caused by the fact that feeding dietary amino acid concentrations greater than the requirement results in an excess of amino acids that are catabolized and thus, the enhanced urea synthesis rate results in greater PUN concentrations (Coma et al., 1995).

In the present study, at the end of Phase 1 (on day 14), there was an increase in PUN concentration as lysine levels increased in the WPC diets, but a decrease in PUN concentration as lysine levels increased in the CAA diets. These results are consistent with those of Davis (1996a) who found that in conventionally weaned pigs, there was an increase in PUN concentration when lysine levels increased in the WPC diets (1.22% or 1.43% available lysine), but a decrease in PUN concentration when lysine levels increased in the CAA diets (1.22% or 1.43% available lysine). In addition, in the present study, pigs fed the CAA diets had lower PUN concentration than those fed the WPC diets and the negative control diet. Similarly, Davis (1996a) reported that in conventionally-weaned pigs, PUN concentrations were lower in pigs fed diets containing CAA than for pigs fed the negative control diet (1.01% available lysine) and the diets containing WPC regardless of the lysine level (1.22% or 1.43% available lysine). These results are consistent with those previously reported that PUN concentration of pigs fed diets containing CAA formulated on ideal protein basis (Chung and Baker, 1992) was lower than that of pigs fed diets containing natural intact protein sources (Lopez et al., 1994; Davis, 1996a). In the present study, since the large amount of the natural intact protein (amino acid) sources (i.e., WPC) in the diet was reduced and crystalline amino acids were substituted to supplement the pig's amino acid requirement on an ideal basis (Chung and Baker, 1992), the low PUN concentrations observed may suggest a lowering of the catabolism of excess amino acids. On the other hand, in the present study, pigs fed the diets containing WPC with higher lysine level (1.68% digestible lysine) showed the greatest PUN concentration. In this study, whey protein concentrate in the diet to attain the higher lysine level may contain many excesses of amino acids that were converted

into urea. This may result in pigs fed the higher lysine diet containing WPC to have higher PUN concentration.

IMPLICATIONS

Although, there has been some success with small additions of CAA to replace limited amounts of natural protein sources, there have been reductions in growth performance associated with higher levels of substitutions. In our study, additions of CAA to the diet of SEW pigs improved performance when compared with pigs fed a low-protein negative control diet, but depressed performance when compared with pigs fed the higher lysine WPC diets. In general, the results of the present study indicate that adding CAA to the diet of SEW pigs improved performance when compared with pigs fed a low protein negative control diet, but did not produce equivalent performance when compared with pigs fed diets containing WPC.

Table 4.1 Diet composition (%), as fed basis[a].

	Lysine Source				
	Control	WPC[b]		CAA[b]	
	Digestible Lysine, %				
Item	1.12	1.40	1.68	1.40	1.68
Yellow corn	23.00	23.00	23.00	23.00	23.00
Lactose	6.80	5.90	5.02	6.80	6.80
Dehydrated whey	21.96	21.96	21.96	21.96	21.96
Steam-rolled oats	10.00	10.00	10.00	10.00	10.00
Menhaden fish meal	8.00	8.00	8.00	8.00	8.00
WPC, 77% CP[b]	-	6.36	12.62	-	-
Corn starch	5.28	2.62	-	4.79	4.03
Sucrose	5.28	2.62	-	4.78	4.02
Dried skim milk	5.00	5.00	5.00	5.00	5.00
AP-920[c]	5.00	5.00	5.00	5.00	5.00
Egg protein	4.00	4.00	4.00	4.00	4.00
Soybean oil	3.00	3.00	3.00	3.00	3.00
Calcium carbonate	.02	-	-	.02	.03
Dicalcium phosphate	.80	.71	.57	.82	.79
Lysine·HCl	-	-	-	.35	.71
Threonine	-	-	-	.18	.36
Tryptophan	.01	-	-	.06	.11
Methionine	.04	.02	.02	.20	.36
Tyrosine	-	-	-	-	.05
Phenylalanine	-	-	-	-	.07
Valine	-	-	-	.05	.24
Leucine	-	-	-	-	.21
Isoleucine	-	-	-	.16	.33
Histidine	-	-	-	-	.12
Neoterramycin[d]	1.00	1.00	1.00	1.00	1.00
Ethoxyquin	.03	.03	.03	.03	.03
Berry flavor	.10	.10	.10	.10	.10
Zinc oxide	.30	.30	.30	.30	.30
Vitamin-min. premix[e]	.38	.38	.38	.38	.38
Biotin supplement	.001	.001	.001	.001	.001

[a] Diets were formulated to contain .90% Ca and .79% P and to exceed the NRC (1988) standards for all nutrients.

[b] WPC:whey protein concentrate; CAA; crystalline amino acid mixture.

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

[d] Contained 22.04 g of neomycin and 11.02g of oxytetracycline per kg.

[e] Vitamins and minerals met or exceeded the (1988) requirements.

Table 4.2. Composition of Transition and Phase 2 diet[a].

	Diets	
Ingredient, %	Transition	Phase 2
Yellow corn	48.79	55.08
Lactose	-	10.00
Dehydrated whey	20.00	-
Soybean meal, 48% CP	12.75	22.25
Menhaden fish meal	8.00	5.00
AP-920[b]	2.50	-
AP-301[b]	1.50	2.00
Soybean oil	4.00	2.50
Calcium carbonate	.15	.27
Dicalcium phosphate	.60	1.43
Lysine·HCl	-	.15
Threonine	-	.05
Methionine	.10	.12
Neoterramycin[c]	1.00	-
Ethoxyquin	.03	.03
Sodium chloride	.20	.30
Tylan 40-sulfa[d]	-	.12
Copper sulfate $5H_2O$	-	.05
Zinc oxide	-	.30
Micro curb		.10
Vit. TM premix[e]	.38	.25

[a] As fed basis. Diets were formulated to contain 1.40% lysine, .85% Ca and .75% P in Transition phase; 1.35% lysine, .80% Ca, and .70% P in Phase 2, and to exceed the NRC (1988) standards for all nutrients.

[b] AP-920: Spray-dried plasma protein; AP-301: Spray-dried blood meal; American Protein Corp., Ames, IA.

[c] Contained 22.04 g of neomycin and 11.02 g of oxytetracycline per kg.

[d] Contained 40g of tylosin and 40g of sulfamethazine per kg.

[e] Vitamins and minerals met or exceeded the NRC (1988) requirements.

Table 4.3 Chemical amino acid analysis of experimental diets fed during Phase 1[a].

	Lysine Source				
	Control	WPC		CAA	
	Digestible Lysine, %				
Item	1.12	1.40	1.68	1.40	1.68
Crude Protein, total	18.14	24.02	27.58	19.63	20.54
Lysine	1.17	1.75	2.08	1.51	1.79
Tryptophan	.27	.43	.53	.34	.34
Threonine	.83	1.15	1.34	1.03	1.19
Methionine	.42	.56	.62	.57	.73
Cysteine	.39	.58	.69	.57	.41
Valine	.97	1.30	1.52	1.07	1.22
Isoleucine	.75	1.05	1.26	.92	1.08
Phenylalanine	.80	1.06	1.18	.85	.89
Tyrosine	.60	.83	.93	.65	.68
Leucine	1.57	2.29	2.79	1.66	1.78
Arginine	.89	1.12	1.17	.92	.93
Histidine	.44	.58	.65	.49	.58
Glycine	.75	.90	.99	.79	.78
Proline	1.02	1.29	1.50	1.06	1.06
Alanine	.97	1.30	1.50	1.03	1.01
Glutamic acid	2.65	3.55	4.15	2.73	2.76
Serine	.80	1.07	1.16	.82	.83
Aspartic acid	1.56	2.25	2.66	1.65	1.65
Ornithine	.01	.02	.02	.02	.02
Taurine	.12	.12	.11	.12	.14
Hydroxyproline	.08	.07	.08	.08	.08
Hydroxylysine	.01	-	.02	.01	.01
Lanthionine	-	.02	.02	.01	.01

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

Table 4.4. Effect of lysine source and level on performance and plasma urea N of segregated early-weaned pigs[a].

	Lysine Source					
	Control	WPC[b]		CAA[b]		
	Digestible Lysine					
Item	1.12	1.40	1.68	1.40	1.68	SEM
d 0 to 7						
ADG, g[ch]	124	192	198	173	144	18
ADFI, g	174	203	194	190	169	16
G:F[dhj]	.71	.95	1.01	.92	.85	.04
d 7 to 14						
ADG, g[ch]	289	366	377	352	307	22
ADFI, g	396	407	375	402	349	27
G:F[chj]	.73	.90	1.01	.89	.89	.04
d 0 to 14						
ADG, g[ehk]	207	279	287	262	226	16
ADFI, g	285	305	284	296	259	20
G:F[fhj]	.72	.92	1.01	.90	.87	.02
d 14 to 28						
ADG, g	469	501	501	481	494	20
ADFI, g	612	636	617	627	659	34
G:F	.76	.78	.82	.77	.75	.02
d 28 to 42						
ADG, g[g]	560	670	604	657	593	31
ADFI, g	836	887	839	908	901	59
G:F	.76	.78	.74	.73	.68	.05
d 0 to 42						
ADG, g[i]	425	484	464	467	438	15
ADFI, g	578	609	580	610	606	34
G:F[eh]	.75	.83	.86	.80	.77	.02
PUN, mg/dL[bfhj]						
Day 14	7.8	9.2	11.3	3.3	2.4	.70

[a] Data were means of 4 pens of 4 pigs each. Pigs averaged 4.7 and 23.9 kg at initiation and termination, respectively.

[b] WPC: whey protein concentrate; CAA; crystalline amino acid mixture; PUN: plasma urea nitrogen.

[c] WPC vs CAA (P<.10).

[d] Lysine source x lysine level interaction (P<.09).

[e] WPC vs CAA (P<.05).

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

[g] Lysine level effect (P<.06).

[h] Control vs WPC (P<.01). [i] Control vs WPC (P<.05).

[j] Control vs CAA (P<.01). [k] Control vs CAA (P<.09).

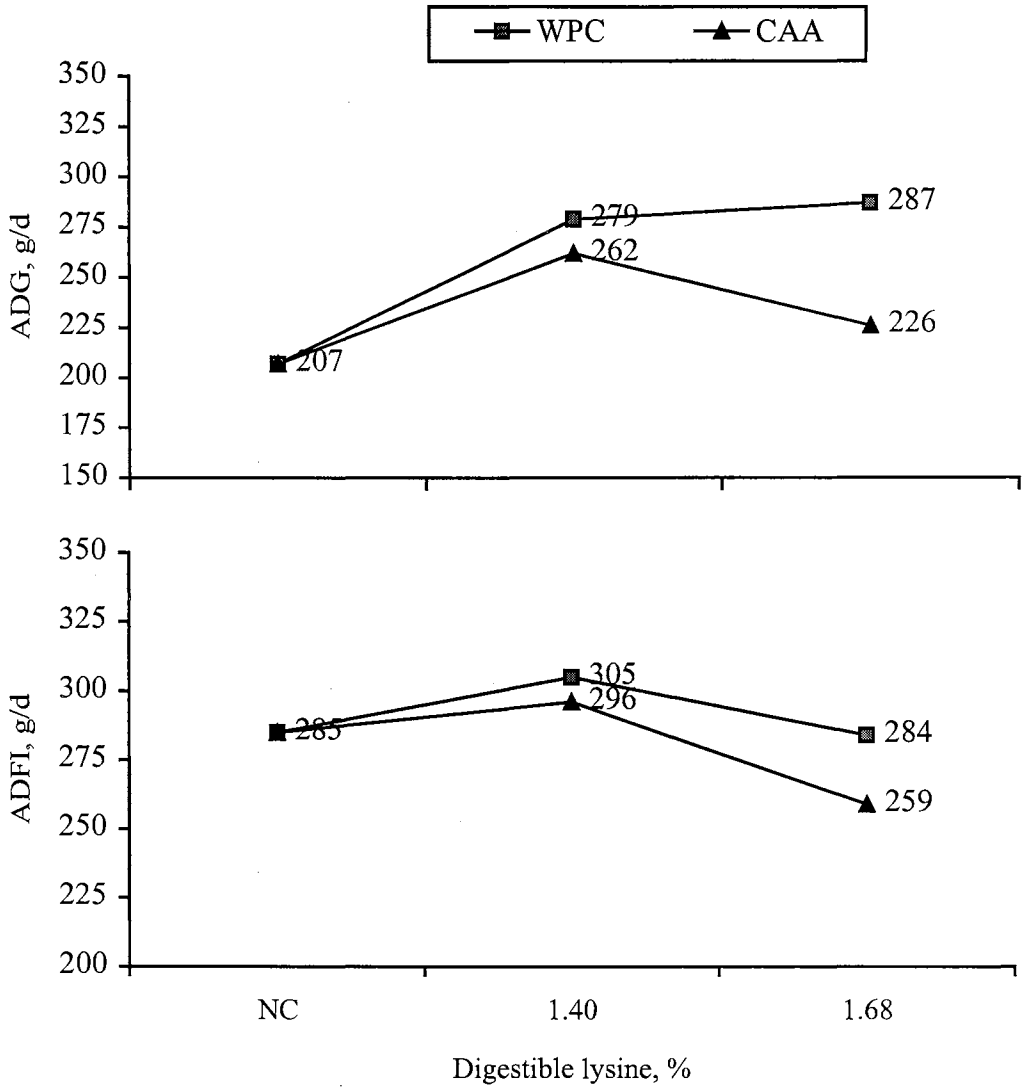

Figure 4.1. Average daily gain (Top panel) and average daily feed intake (Bottom panel) of pigs fed WPC and a mixture of CAA at two different digestible lysine levels during Phase 1 (from d 0 to 14 postweaning) of the experiment.

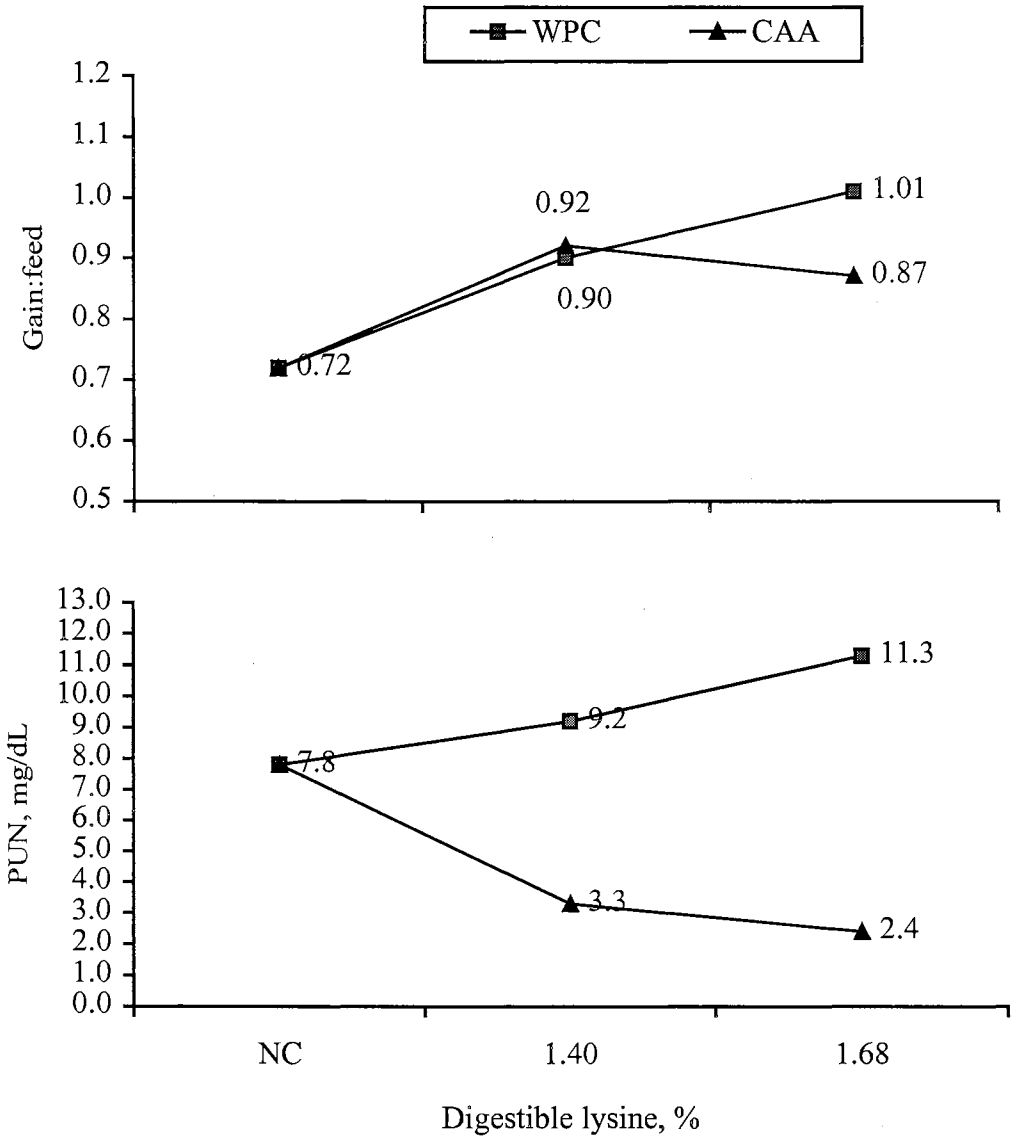

Figure 4.2. Gain:feed (Top panel) of pigs fed WPC and a mixture of CAA at two different digestible lysine levels during Phase 1 (from d 0 to 14 postweaning) and plasma urea nitrogen concentrations (Bottom panel) of pigs fed WPC and a mixture of CAA at two different digestible lysine levels that were collected on d 14 of the experiment.

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CHAPTER V

EFFECTS OF REPLACING WHEY PROTEIN CONCENTRATE (77% CP) WITH CRYSTALLINE AMINO ACIDS ON WEANLING PIG PERFORMANCE

ABSTRACT

Two growth trials involving 204 weanling pigs were conducted to determine the efficacy of replacing whey protein concentrate (WPC, 77% CP) with crystalline amino acids (CAA) on growth performance and plasma urea nitrogen (PUN). In Exp. 1, 84 pigs (20-d old, 5.5 kg initial BW) were allotted to 24 pens (3 to 4 pigs/pen; 4 replicates/treatment) based on initial BW, litter, and sex. The control diet (1.65% Lys) contained 9.6% WPC. In Diet 2, WPC was replaced with an ideal mixture of essential CAA (Lys, Met, Thr, Trp, Ile, and Val). Diets 3-6 were: (3) as Diet 2 + Leu, Ile, Val (LIV); (4) as Diet 2 + Trp, Phe, Tyr (TPT); (5) as Diet 2 + Pro, His, Arg (PHA); and (6) as Diet 2 + CAA added to Diets 3, 4, 5. In Exp. 2, 120 pigs (21-d old, 6.6 kg initial BW) were allotted 20 pens (6 pigs/pen; 5 replicates/treatment) based on initial BW, litter, and sex. The control diet (1.65% Lys) contained 9.6% WPC. In Diet 2, WPC was replaced with an ideal mixture of essential CAA. Diets 3 to 5 were: (3) as Diet 2 + Gly, Glu, Asp (NEAA); (4) as Diet 3 + Trp, Phe, Tyr (TPT); and as Diet 3 + Pro, His, Arg (PHA). In both experiments, the experimental diets fed during Phase 1 (d 0-14) contained 33.08%

corn, 20% dried whey, 10% dehulled oats, 6.57% fish meal, 3.5% spray-dried plasma protein, 2.81% soy protein concentrate, and 1.50% spray-dried blood meal. To monitor any carry over effects from the diets fed during Phase 1, all pigs were fed a common Phase 2 (1.35% Lys) and 3 diet (1.15% Lys). Average daily gain (ADG), ADFI, and G:F were determined weekly and blood samples were collected at the end of Phase 1 to access PUN concentration. In Exp. 1, from d 0 to 14 postweaning, ADG and G:F in pigs fed the control diet were greater ($P<.05$) than those of pigs fed Diet 2. Addition of CAA to Diet 2 tended to improve ($P<.10$) ADG and G:F with the greatest improvement from the addition of TPT. On d 14, PUN was markedly lower ($P<.01$) in pigs fed Diet 2 as compared with pigs fed the control diet. In general, addition of CAA to Diet 2 increased PUN with the greatest increase ($P<.01$) from the addition of LIV. In Exp. 2, from d 0 to 14 postweaning, pigs fed the control diet grew faster ($P<.01$) and were more efficient ($P<.01$) than pigs fed Diet 2. Addition of NEAA, TPT, or PHA to Diet 2 did not affect ($P>.10$) growth performance. On d 14, PUN was markedly lower ($P<.01$) for pigs fed Diet 2 as compared with pigs fed the control diet. Addition of NEAA to Diet 2 increased ($P<.01$) PUN but the greatest increase ($P<.01$) in PUN was observed with addition of either TPT or PHA to Diet 3. These results suggest that replacement of WPC with an ideal blend of CAA reduced pig performance during Phase 1 of the nursery period.

INTRODUCTION

The amino acid requirements of swine can be supplied by natural intact protein sources or it can be furnished by crystalline amino acids (CAA). Crystalline amino acids

can be added to low-protein swine diets to overcome potential amino acids deficiencies (Tuitoek et al., 1997) and to improve the amino acid balance. In addition, the supplementation of crystalline amino acids to low protein diets is one method to decrease nitrogen excretion (Lenis, 1989; Carter et al., 1996).

Previous research (Experiment 3: Chapter IV) at Oklahoma State University conducted to evaluate the potential efficacy for use of CAA as the source of amino acids in the diets of Phase 1 (from d 0 to 14 postweaning) nursery pigs resulted in reduced growth performance. Similarly, Davis et al. (1997) reported that in weanling pigs, the replacement of WPC with an ideal mixture of CAA resulted in reduced growth performance. The poorer performance of pigs fed the crystalline amino acid diet may have been due to an amino acid imbalance or limited nitrogen for synthesis of dispensable amino acids. Fickler et al. (1994) suggested that in order to enhance growth rate and nitrogen retention, the amount of dispensable amino acids in a chemically-defined diet should be increased and then the pattern of indispensable amino acids should be further improved in order to attain an ideal protein. Furthermore, Roth et al. (1994) suggested that although, alanine, aspartic acid, glycine, or serine are fully dispensable for the growing pig, arginine, glutamine, or proline are indispensable and must be provided in certain amounts. Therefore, the objectives of this study were to (1) evaluate the efficacy of replacing whey protein concentrate (WPC, 77% CP) with crystalline amino acids in weanling pig diets on growth performance and plasma urea nitrogen (PUN), and to (2) evaluate if the specific additions of essential and non-essential crystalline amino acids to an ideal blend of amino acids in a low-protein diet could improve growth performance of weanling pigs.

MATERIALS AND METHODS

Two trials involving 204 weanling pigs (Yorkshire, Hampshire, and Yorkshire x Hampshire) were conducted to determine the efficacy of replacing whey protein concentrate (WPC, 77% CP) with crystalline amino acids (CAA) on growth performance and plasma urea nitrogen (PUN). In Experiment 1, a total of 84 pigs (20 days of age and 5.5 kg initial BW) was sorted by weight and divided into four groups (blocks). The first two weight groups contained 24 pigs and the next two weight groups included 18 pigs, respectively. Pigs within each weight group were allotted randomly to six equal subgroups (three or four pigs/pen) with stratification based on sex and litter. The pens within each of the four weight groups were randomly assigned to six dietary treatments (4 pens/treatment). The composition of the experimental diets is shown in Table 5.1. The control diet was a fortified corn-soybean meal-dried whey diet containing 9.6% whey protein concentrate (WPC) as a natural amino acid source. Diets 2-6 were formulated to evaluate the effects of replacing WPC with crystalline amino acids. Diets 2-6 were: (2) in Diet 2 the WPC component in Diet 1 (Control) was replaced with an ideal mixture of crystalline amino acids (lysine, methionine, threonine, tryptophan, isoleucine, and valine; IAA) (Chung and Baker, 1992), (3) as Diet 2 with crystalline leucine, isoleucine, and valine (LIV) added to approximate ratios to lysine in the control diet, (4) as Diet 2 with crystalline tryptophan, phenylalanine, and tyrosine (TPT) added to approximate ratios to lysine in the control diet, (5) as Diet 2 with crystalline proline, histidine, and arginine (PHA) added to approximate ratios to lysine in the control diet, and (6) as Diet 2 with

crystalline amino acid additions to Diets 3, 4, and 5. Calculated chemical composition of the six experimental diets fed during Phase 1 is shown in Table 5.2.

All six experimental diets were formulated to contain 1.65% lysine (1.44% digestible lysine), 33.08% corn, 20% dried whey, 10% dehulled oats, 6.57% menhaden fish meal, 3.5% spray dried plasma protein (APC 920), 2.81% soy protein concentrate, and 1.50% spray dried blood meal (APC 301G). All experimental diets except the control diet contained glycine, aspartate, and glutamine (NEAA) as dispensable nitrogen sources. Potassium bicarbonate ($KHCO_3$) was added to Diets 2 to 6 to approximate the electrolyte balance in the control diet. Substitutions were made on equal lysine basis at the expense of sucrose and cornstarch. Pigs were fed the six experimental diets from day 0 to 14 postweaning (Phase 1). To monitor any carryover effects from Phase 1, pigs were fed a common Phase 2 diet (1.35% lysine) from day 14 to 28 and a Phase 3 diet (1.15% lysine) from day 28 to 35 postweaning (Table 5.3).

In Experiment 2, a total of 120 pigs (21 days of age and 6.6 kg initial BW) was sorted by weight and divided into four groups (blocks). Pigs within each weight group were allotted to six equal subgroups (six pigs per pen) with stratification based on sex and litter. The pens within each of the four weight groups were assigned randomly to five dietary treatments (4 pens/treatment). The composition of the experimental diets is shown in Table 5.5. The control diet, the same as that used in Experiment 1, was a fortified corn-soybean meal-dried whey diet containing 9.6% whey protein concentrate (WPC, 77%) as a natural amino acid source. Diets 2-5 were formulated to evaluate the effects of replacing WPC with crystalline amino acids. Diets 2-5 were: (2) in Diet 2, the WPC component in Diet 1 (Control) was replaced with an ideal mixture (Chung and

Baker, 1992) of essential crystalline amino acids (lysine, threonine, methionine, isoleucine, tryptophan, and valine; IAA), (3) as Diet 2 with crystalline glycine, glutamic acid, and aspartate (NEAA) to approximate NEAA:CP ratio in the control diet, (4) as Diet 3 with crystalline tryptophan, phenylalanine, and tyrosine (TPT) added to approximate ratios to lysine in the control diet, and (5) as Diet 3 with crystalline proline, histidine, and arginine (PHA) added to approximate ratios to lysine in the control diet. Calculated chemical compositions of the five experimental diets fed during Phase 1 are shown in Table 5.6.

All five experimental diets were formulated to contain 1.65% total lysine (1.44% digestible lysine), 33.08% corn, 20% dried whey, 10% dehulled oats, 6.57% menhaden fish meal, 3.5% spray dried plasma protein (APC 920), 2.81% soy protein concentrate, and 1.50% spray dried blood meal (APC 301G). All five experimental diets except the control diet and Diet 2 contained glycine, aspartate, and glutamine (NEAA) as dispensable nitrogen sources. Potassium bicarbonate ($KHCO_3$) was added to Diets 3 to 5 to approximate electrolyte balance in control diet. Substitutions were made on equal lysine basis at the expense of sucrose and cornstarch. Pigs were fed the five experimental diets from d 0 to 14 postweaning (Phase 1). Upon completion of Phase 1, to monitor any carry over effects of the diet fed during Phase 1, pigs were fed a common Phase 2 diet (1.35% lysine) from d 14 to 28 and a Phase 3 diet (1.15% lysine) from d 28 to 42 postweaning (Table 5.3).

In both experiments, pigs were housed in an environmentally controlled off-site nursery in elevated (1.09 m x 1.52 m) pens with woven wire flooring. The initial

temperature of 31°C was subsequently decreased 1°C per week. Pigs in each pen had ad libitum access to one nipple waterer and a three-hole feeder. Pig body weight and feed intake were determined weekly to evaluate average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (G:F). Blood samples were taken via anterior vena cava puncture at the end of Phase 1 (d 14) of the experiment and plasma was analyzed for urea N concentration using The Roche® Reagent for PUN (Roche Diagonic Systems, Somerville) and a COBAS FARA II clinical analyzer (Roche Diagonic Systems, Branchburg, NJ.).

In both experiments, performance data and plasma urea nitrogen were analyzed according to a randomized complete block design (Steel and Torrie, 1980) with pen as the experimental unit and blocks based on initial body weight. Analysis of variance was performed using the GLM procedures of SAS (1988). Pre-planned non-orthogonal contrasts were used to compare treatment means.

RESULTS

Experiment 1

The effects of addition of crystalline amino acids to low-crude protein diets for weanling pigs on ADG, ADFI, G:F, and PUN during Experiment 1 are shown in Table 5.4. In Experiment 1, from day 0 to 7 postweaning, pigs fed the control diet containing 9.6% whey protein concentrate as a natural intact amino acid source had numerically higher average daily gain (ADG) than pigs fed the low protein, crystalline amino acids

diets; however, this increase in ADG was greater (P<.10) only compared with pigs fed Diets 3 and 6. Average daily feed intake (ADFI) and gain:feed (G:F) were not significantly affected (P>.10) by the addition of crystalline amino acids.

From day 7 to 14 postweaning, pigs fed the control diet containing 9.6% WPC as a natural intact amino acid source had greater ADG (P<.05) and G:F than pigs fed Diet 2 which contained an ideal blend of amino acids. Addition of crystalline amino acids to Diet 2 tended to improve ADG and G:F with greatest improvement for pigs fed Diet 6. Average daily gain (ADG) of pigs fed Diet 6 was greater (P<.05) than that of pigs fed Diet 2. In addition, G:F of pigs fed Diet 6 was greater (P<.05) than that of pigs fed Diet 5. However, ADFI was not significantly affected (P<.10) by the addition of crystalline amino acids.

The effects of crystalline amino acids to low-protein diets for weanling pigs on ADG, ADFI, and G:F during Phase 1 (from d 0 to 14 postweaning) in Experiment 1 are shown in Figure 5.1 and 5.2. From day 0 to 14 postweaning (Phase 1), pigs fed the control diet containing 9.6% WPC as a natural intact amino acid source grew 21% faster (P<.05) and gained 12% more efficiently (P<.05) per kg of feed than pigs fed Diet 2 which contained an ideal blend of crystalline amino acids. However, there was no significant difference (P>.10) in ADFI between pigs fed the control diet and pigs fed Diet 2. During Phase 1, addition of crystalline amino acids to Diet 2 tended to improve ADG and G:F with the greatest improvement from the addition of tryptophan, phenylalanine, and tyrosine (TPT). However, ADG, ADFI, and G:F were not significantly different (P>.10) among the dietary treatments containing supplemented crystalline amino acids added to the ideal blend.

The effects of crystalline amino acids to low protein diets for weanling pigs on PUN during Phase 1 (from d 0 to 14 postweaning) in Experiment 1 are shown in Figure 5.2. At the end of Phase 1, plasma urea nitrogen (PUN) concentration was markedly lower (P<.01) in pigs fed Diet 2 as compared with those fed the control diet containing 9.6% WPC. In general, the addition of crystalline amino acids to Diet 2 containing an ideal blend of amino acids increased (P<.01) PUN concentration with the greatest increase (P<.01) occurring when leucine, isoleucine, and valine (LIV) were added.

Diets fed during Phase 1 (from d 0 to 14 postweaning) had no effect (P>.10) on growth performance during Phase 2 (from d 14 to 28 postweaning). From day 14 to 35 postweaning, there were only small differences in growth performance among dietary treatments. For the entire 35-d experimental period, pigs fed the control diet containing 9.6% WPC during Phase 1 grew faster (P<.10) and gained more efficiently than those fed Diet 2 containing an ideal blend of amino acids. Among the additions of crystalline amino acids to the ideal blend during Phase 1, the addition of tryptophan, phenylalanine, and tyrosine (TPT) to Diet 2 which contained an ideal blend of crystalline amino acids elicited the greatest improvement in ADG and G:F over the 35-d experimental period. Also, ADG and G:F of pigs fed the addition of tryptophan, phenylalanine, and tyrosine (TPT) to Diet 2 were greater (P<.10 and P<.01, respectively) than those of pigs fed Diet 2 which contained an ideal blend of amino acid.

Experiment 2

The effects of crystalline amino acids to low-crude protein diets for weanling pigs on ADG, ADFI, G:F, and PUN during Experiment 2 are shown in Table 5.7. In Experiment 2, from day 0 to 7 postweaning, pigs fed the control diet containing 9.6%

WPC as the natural intact amino acid source had greater (P<.01) ADG and G:F than pigs receiving the crystalline amino acids diets. Gain:feed (G:F) of pigs fed Diet 2 containing IAA or Diet 3 containing NEAA were lower (P<.01) than that of pigs fed Diet 4 containing TPT and Diet 5 containing PHA. However, ADFI was not significantly affected (P<.10) by the addition of crystalline amino acids.

From day 7 to 14 postweaning, pigs fed the control diet containing 9.6% WPC as the natural intact amino acid source had greater (P<.01) ADG than pigs fed Diet 3 containing NEAA, Diet 4 containing TPT, or Diet 5 containing PHA. Pigs fed the control diet containing 9.6% WPC or Diet 2 containing IAA had greater (P<.05) ADFI than pigs fed Diet 4 containing TPT or Diet 5 containing PHA. However, G:F was not significantly affected (P<.10) by the addition of crystalline amino acids.

The effects of crystalline amino acids to low-protein diets for weanling pigs on ADG, ADFI, and G:F during Phase1 in Experiment 2 are shown in Figure 5.3 and 5.4. During Phase 1 (from d 0 to 14 postweaning), pigs fed the control diet containing 9.6% WPC as the natural intact amino acid source had greater (P<.01) ADG than pigs fed the crystalline amino acid diets. Pigs fed the control diet containing 9.6% WPC had greater (P<.01) G:F than pigs fed Diet 2 containing IAA, or Diet 3 containing NEAA. Average daily feed intake (ADFI) of pigs fed the control diet containing 9.6% WPC or Diet 2 containing IAA was greater (P<.05) than that of pigs fed Diet 4 containing TPT. In addition, ADFI of pigs fed Diet 2 containing IAA was greater (P<.05) than that of pigs fed Diet 5 containing PHA.

During Phase 2 (from d 14 to 28 postweaning), ADG and ADFI were not significantly affected (P<.10) by the addition of crystalline amino acids during Phase 1.

However, G:F of pigs fed the control diet containing 9.6% WPC was lower (P<.05) than that of pigs fed Diet 2 containing IAA.

During Phase 3 (from d 28 to 42 postweaning), ADG and ADFI were not significantly affected (P>.10) by the addition of crystalline amino acids during Phase 1. However, G:F of pigs fed the Diet 2 containing IAA was greater (P <.05) than that of pigs fed the Diet 3 containing NEAA or Diet 4 containing TPT.

For the entire 42-d experiment, pigs fed the control diet containing 9.6% WPC had greater (P<.01) ADG than pigs fed Diet 3 containing NEAA. Gain:feed (G:F) of pigs fed the control diet containing 9.6% WPC or Diet 2 containing IAA was greater (P<.05) than that of pigs fed the Diet 3 containing NEAA. In addition, G:F of pigs fed Diet 2 containing IAA was greater (P<.05) than that of pigs fed Diet 4 containing TPT. However, ADFI was not significantly affected (P<.10) by the addition of crystalline amino acids.

The effects of crystalline amino acids to low-protein diets for weanling pigs on PUN during Phase 1 in Experiment 2 are shown in Figure 5.4. At the end of Phase 1 (d 14), plasma urea nitrogen concentrations were markedly lower (P<.01) for pigs fed Diet 2 containing IAA as compared with those fed the control diet containing 9.6% WPC. In general, addition of crystalline amino acids to Diet 2 increased (P<.01) PUN concentration, with the greatest increase (P<.01) observed for pigs fed Diet 5 containing PHA.

DISCUSSION

In the present study, pigs fed WPC as a natural intact amino acid source in the diet grew faster and were more efficient than pigs fed an ideal blend of crystalline essential amino acids (CAA) during Phase 1 (from d 0 to 14 postweaning) in Experiment 1 and 2. These results are consistent with those of the previous study (Experiment 3: Chapter IV), which observed poor growth performance in SEW pigs during Phase 1 (from d 0 to 14 postweaning) when the WPC component was replaced by an ideal mixture of CAA (Chung and Baker, 1992) as the amino acid source. Similarly, Davis et al. (1997) also observed that in conventionally weaned pigs, substitution of amino acids in WPC with crystalline amino acids resulted in depressed ADG and feed efficiency during Phase 1 (from d 0 to 14 postweaning). In the present study, the effects of specific additions of crystalline essential and nonessential amino acids to an ideal blend of amino acids in a low-protein diet during Phase 1 produced inconsistent results. During Phase 1, the addition of LIV, TPT, or PHA to Diet 2 containing IAA tended to increase growth performance in Experiment 1, but the addition of NEAA, TPT, or PHA to Diet 2 containing IAA did not affect growth performance in Experiment 2. More studies are needed to identify whether the specific additions of crystalline essential and nonessential amino acids to an ideal blend of amino acids in a low-protein diet are able to enhance growth performance during Phase 1 of the nursery period.

A deficiency in the amount of dispensable amino acids could be a plausible explanation for the poor growth performance observed in pigs fed the diet in which WPC was replaced with an ideal mixture of essential crystalline amino acids in the present

study. Fickler et al. (1994) reported that a 24% decrease in growth rate of 10-kg pigs fed a chemically-defined diet containing essential amino acids as recommended by Chung and Baker (1992) and a complete mixture of nonessential amino acids (including alanine, aspartic acid, glutamic acid, glycine, proline, and serine) when compared to pigs fed the control diet (containing grains, soybean meal, fish meal, and skim milk) as the source of amino acids. In the same study, Fickler et al. (1994) suggested that, in order to increase growth rate and nitrogen retention, the amount of dispensable amino acids in a chemically-defined diet should be increased and the pattern of indispensable amino acids should be improved in order to attain an ideal protein.

Plasma urea nitrogen concentration is used as a predictive indicator of amino acid nutrition status. When an amino acid is limiting or at deficient levels in diets, it restricts the utilization of other non-limiting or sufficient levels of amino acids for protein synthesis; thereby these surplus amino acids are utilized for urea synthesis resulting in increased PUN concentration. On the other hand, when dietary amino acid concentrations greater than the requirement are supplied, PUN concentrations of pigs tend to be increased (Lewis et al., 1977, 1981; Coma et al., 1995).

In the present study, at the end of Phase 1 of Experiment 1 and 2, PUN concentration was markedly lower in pigs fed the diet containing an ideal blend of essential CAA as compared with those fed the control diet containing 9.6% WPC as a natural intact amino acid source. These results are consistent with those previously reported that PUN concentration of pigs fed diets containing synthetic amino acids formulated on ideal protein basis (Chung and Baker, 1992) was lower than that of pigs fed diets containing natural intact protein sources (Lopez et al., 1994; Davis, 1996). In

the present study, since the large amount of the natural intact amino acid source (i.e., 9.6% WPC) was replaced with CAA in Diet 2 formulated on an ideal basis (Chung and Baker, 1992), the lower PUN concentrations observed may suggest a lowering of the catabolism of excess amino acids. On the other hand, in the present study, the addition of CAA to Diet 2 containing an ideal blend of amino acids increased PUN concentration, with the greatest increase occurring when crystalline LIV were added in Experiment 1 and when crystalline NEAA plus PHA were added in Experiment 2, respectively. These observations may suggest that greater catabolism of excess amino acids occurred which were converted into urea.

IMPLICATIONS

Substitution of WPC with an ideal blend of crystalline amino acids during Phase 1 (from d 0 to 14 postweaning) reduced pig performance. In the present study, the effects of specific additions of crystalline essential and nonessential amino acids to an ideal blend of amino acids in a low-protein diet during Phase 1 were inconsistent. During Phase 1, the addition of LIV, TPT, or PHA to Diet 2 containing IAA tended to increase growth performance in Experiment 1, but the addition of NEAA, TPT, or PHA to Diet 2 containing IAA did not affect growth performance in Experiment 2. More studies are needed to identify whether the specific additions of crystalline essential and nonessential amino acids to an ideal blend of amino acids in a low protein diet are able to enhance growth performance during Phase 1 of the nursery period.

Table 5.1. Composition of experimental diets (Phase 1-Exp. 1).

	Diet[a]					
	1	2	3	4	5	6
	AA Source					
Ingredient, %	WPC	IAA	IAA + L, I, V	IAA + T, P, T	IAA + P, H, A	All AA
Fixed ingredients[b]	77.46	77.46	77.46	77.46	77.46	77.46
Lactose	3.29	4.65	4.65	4.65	4.65	4.65
WPC, 77%	9.60	-	-	-	-	-
$Ca_2H_2(PO_4)_2$	1.04	1.40	1.40	1.40	1.40	1.40
Limestone	.04	.06	.06	.06	.06	.06
L-Lysine HCl	-	.54	.54	.54	.54	.54
DL-Methionine	.08	.34	.34	.34	.34	.34
L-Threonine	-	.29	.29	.29	.29	.31
L-Tryptophan	-	.10	.10	.10	.10	.10
L-Valine	-	.14	.14	.14	.14	.14
L-Isoleucine	-	.30	.30	.30	.30	.30
Glycine	-	1.08	1.67	1.33	1.17	2.17
Aspartic acid	-	1.08	1.67	1.33	1.17	2.17
Glutamic acid	-	1.08	1.67	1.33	1.17	2.17
L-Leucine	-	-	.60	-	-	.60
L-Valine	-	-	.19	-	-	.19
L-Isoleucine	-	-	.03	-	-	.03
Phenylalanine	-	-	-	.135	-	.135
Tyrosine	-	-	-	.135	-	.135
Tryptophan	-	-	-	.040	-	.040
Proline	-	-	-	-	.30	.30
Histidine	-	-	-	-	.15	.15
Arginine	-	-	-	-	.13	.13
Other[c]	4.38	4.08	4.28	4.38	4.28	4.93
Sucrose	2.06	3.60	2.12	2.57	2.84	.65
Corn starch	2.06	3.60	2.12	2.57	2.84	.65
$KHCO_3$[d]	-	.19	.19	.19	.25	.26

[a] WPC, Basal + whey protein concentrate (Control); Diet 2, Basal + synthetic essential AAs + synthetic nonessential AAs + electrolyte; Diet 3, as Diet 2 + Leu + Ile + Val; Diet 4, as Diet 2 + Trp + Phe + Tyr; Diet 5, as Diet 2 + His + Arg + Pro; Diet 6, as Diet 2 + AAs added to Diets 3, 4, and 5.

[b] Contained 33.08% corn, 20% dried whey, 10% dehulled oats, 6.57% menhaden fish meal, 3.5% spray dried plasma protein (APC 920), 2.81% soy protein concentrate, and 1.50% spray dried blood meal (APC 301G).

[c] Contained .10% flavor, .03% ethoxyquin, 2.15-3.00% soybean oil, .20% salt, .30% OSU trace mineral and vitamin premix, .30% zinc oxide, and 1.00% neo-terramycin.

[d] Added to approximate (Na+K)-Cl balance in control diet.

Table 5.2. Chemical composition of diets (Phase 1-Exp. 1).

	Diet[a]					
	1	2	3	4	5	6
	AA Source					
Ingredient	WPC	IAA	IAA + L, I, V	IAA + T, P, T	IAA + P, H, A	All AA
ME, kcal/kg	3308	3308	3308	3308	3308	3308
CP, %	24.5	21.2	22.7	21.8	21.4	24.0
Total AA, %						
Lysine	1.65	1.62	1.62	1.62	1.62	1.62
Threonine	1.20	1.10	1.10	1.10	1.10	1.12
Methionine	.51	.65	.65	.65	.65	.65
Cystine	.51	.33	.33	.33	.33	.33
Met. + Cys	1.01	.98	.98	.98	.98	.98
Tryptophan	.35	.29	.29	.33	.29	.33
EAA:CP	.52	.52	.52	.52	.52	.52
Digestible AA, %						
Lysine	1.44	1.44	1.44	1.44	1.44	1.44
Threonine	.96	.93	.93	.93	.93	.95
Methionine	.44	.60	.60	.60	.60	.60
Tryptophan	.30	.26	.26	.30	.26	.30
AA ratios (% of digestible lysine)						
Lysine	100	100	100	100	100	100
Threonine	66	65	65	65	65	66
Methionine	31	42	42	42	42	42
Met. + Cys.	60	60	60	60	60	60
Tryptophan	21	18	18	21	18	21
Isoleucine	62	60	62	60	60	62
Leucine	145	104	145	104	104	145
Valine	81	68	81	68	68	81
Histidine	43	33	33	33	43	43
Arginine	68	58	58	58	68	68
Phe. + Tyr.	112	93	93	112	93	112
Ca, %	.91	.91	.91	.91	.91	.91
P, %	.80	.80	.80	.80	.80	.80

[a] WPC, Basal + whey protein concentrate (Control); Diet 2, Basal + synthetic essential AAs + synthetic nonessential AAs + electrolyte; Diet 3, as Diet 2 + Leu + Ile + Val; Diet 4, as Diet 2 + Trp + Phe + Tyr; Diet 5, as Diet 2 + Pro + His + Arg; Diet 6, as Diet 2 + AAs added to Diets 3, 4, and 5.

Table 5.3. Composition of experimental diets (Phase 2 and 3-Exp. 1 and 2).

	Diet[a]	
	Phase 2	Phase 3
	Lysine, %	
Ingredient, %	1.35	1.15
Corn, ground	57.92	68.96
Soybean meal, 48%	22.25	27.50
Lactose	10.0	-
Menhaden fish meal	5.0	-
AP-301G[b]	2.0	-
L-Lysine HCl	.15	.15
DL-Methionine	.12	-
L-Threonine	.05	-
Limestone	.27	.60
Dicalcium phosphate	1.43	1.90
Salt	.30	.42
$CuSO_4$	.10	.10
Tylan 40-Sulfa[c]	1.25	1.25
Vitamin TM premix[d]	.125	.125

[a] Diets were formulated on an as fed basis and to meet or exceed the NRC (1988) standards for all nutrients.

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

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

[d] Vitamins and minerals meet or exceed the NRC (1988) requirements.

Table 5.4. The effects of crystalline amino acid additions to low-crude protein diets for weanling pigs (Exp. 1)[a].

	Diet[b]						
	1	2	3	4	5	6	
	AA Source						
Item	WPC	IAA	IAA + L, I, V	IAA + T, P, T	IAA + P, H, A	All AA	SEM
Day 0 to 7							
ADG, g	222[c]	189[cd]	180[d]	213[cd]	208[cd]	175[d]	16.48
ADFI, g	199	184	167	190	193	166	15.22
Gain:feed	1.09	1.00	1.06	1.11	1.08	1.06	.054
Day 7 to 14							
ADG, g	385[e]	313[f]	352[ef]	378[ef]	358[ef]	386[e]	21.80
ADFI, g	390[cd]	356[c]	380[cd]	395[cd]	417[d]	389[cd]	23.33
Gain:feed	.99[ef]	.87[ef]	.93[ef]	.95[ef]	.86[e]	.99[f]	.050
Day 0 to 14							
ADG, g	304[e]	251[f]	266[ef]	296[ef]	283[ef]	281[ef]	16.60
ADFI, g	295	270	274	293	305	277	17.19
Gain:feed	1.03[e]	.92[f]	.97[ef]	1.01[ef]	.93[ef]	1.01[ef]	.037
Day 14 to 28							
ADG, g	497	488	531	523	490	516	17.74
ADFI, g	671	680	704	677	679	678	23.93
Gain:feed	1.35	1.40	1.33	1.30	1.38	1.32	.047
Day 14 to 35							
ADG, g	517[cd]	486[d]	533[c]	530[cd]	504[cd]	539[c]	18.00
ADFI, g	747	753	769	749	746	770	21.80
Gain:feed	.69[cd]	.64[c]	.69[cd]	.71[d]	.68[cd]	.70[cd]	.055
Day 0 to 35							
ADG, g	431[c]	392[d]	426[cd]	436[c]	415[cd]	436[c]	15.17
ADFI, g	566	560	571	566	569	573	17.59
Gain:feed	.76[ef]	.70[e]	.75[ef]	.77[f]	.73[ef]	.76[ef]	.045
PUN, mg/dL							
Day 14	7.13[g]	2.88[h]	6.66[g]	4.41[h]	3.88[h]	8.60[g]	.479

[a] Least square means for 4 pens (3-4 pigs/pen) per treatment. Pigs averaged 5.53 and 20.33 kg at trial initiation and termination, respectively.

[b] WPC, Basal + whey protein concentrate (Control); Diet 2, Basal + synthetic essential AAs + synthetic nonessential AAs + electrolyte; Diet 3, as Diet 2 + Leu + Ile + Val; Diet 4, as Diet 2 + Trp + Phe + Tyr; Diet 5, as Diet 2 + Pro + His + Arg; Diet 6, as Diet 2 + AAs added to Diets 3, 4, and 5.

[c,d] Means within same row with different superscripts differ (P<.10).

[e,f] Means within same row with different superscripts differ (P<.05).

[g,h] Means within same row with different superscripts differ (P<.01).

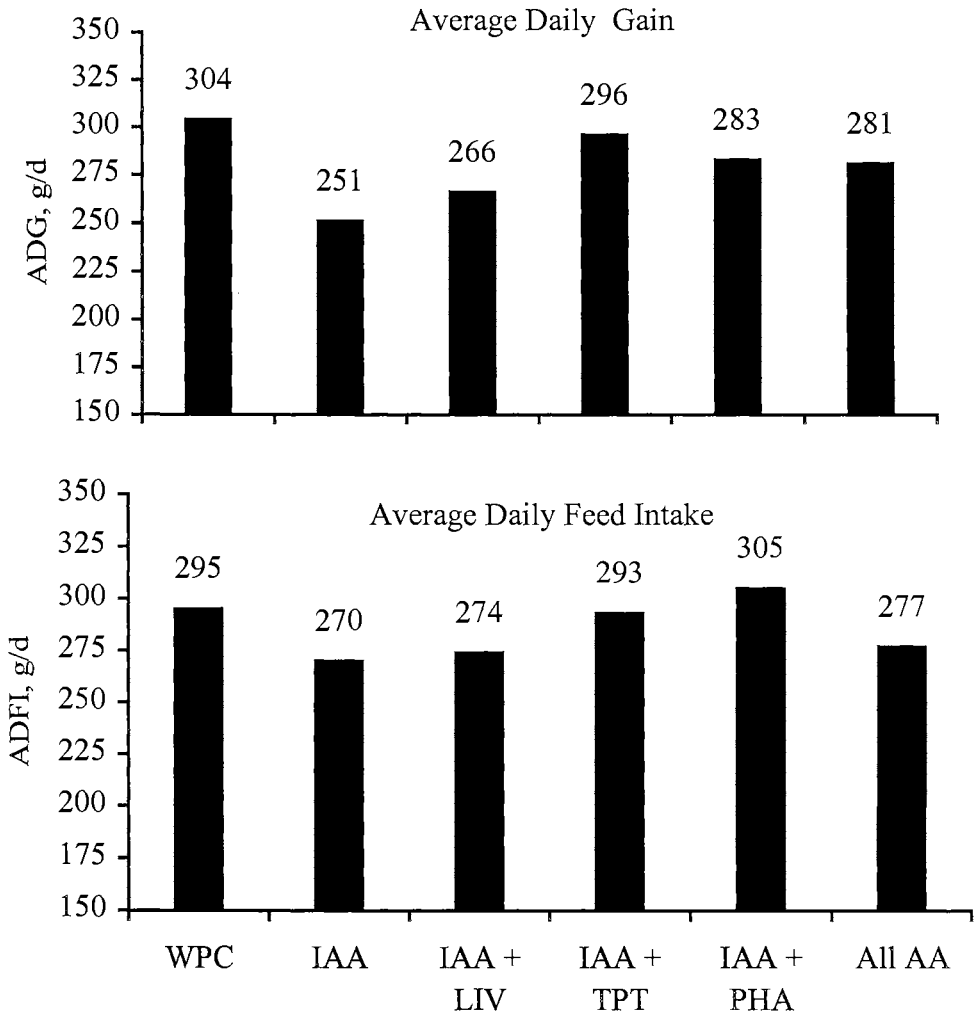

Figure 5.1 Average daily gain (Top panel) and average daily feed intake (Bottom panel) of pigs fed six dietary treatments in Exp. 1. WPC = Basal + whey protein concentrate; IAA = Basal + synthetic essential AA + nonessential AA + electrolyte; IAA + LIV = as IAA +Leu + Ile + Val; IAA + TPT = as IAA + Trp+ Phe + Tyr; IAA + PHA = as IAA + Pro + His + Arg; All AA = as IAA + LIV + TPT + PHA.

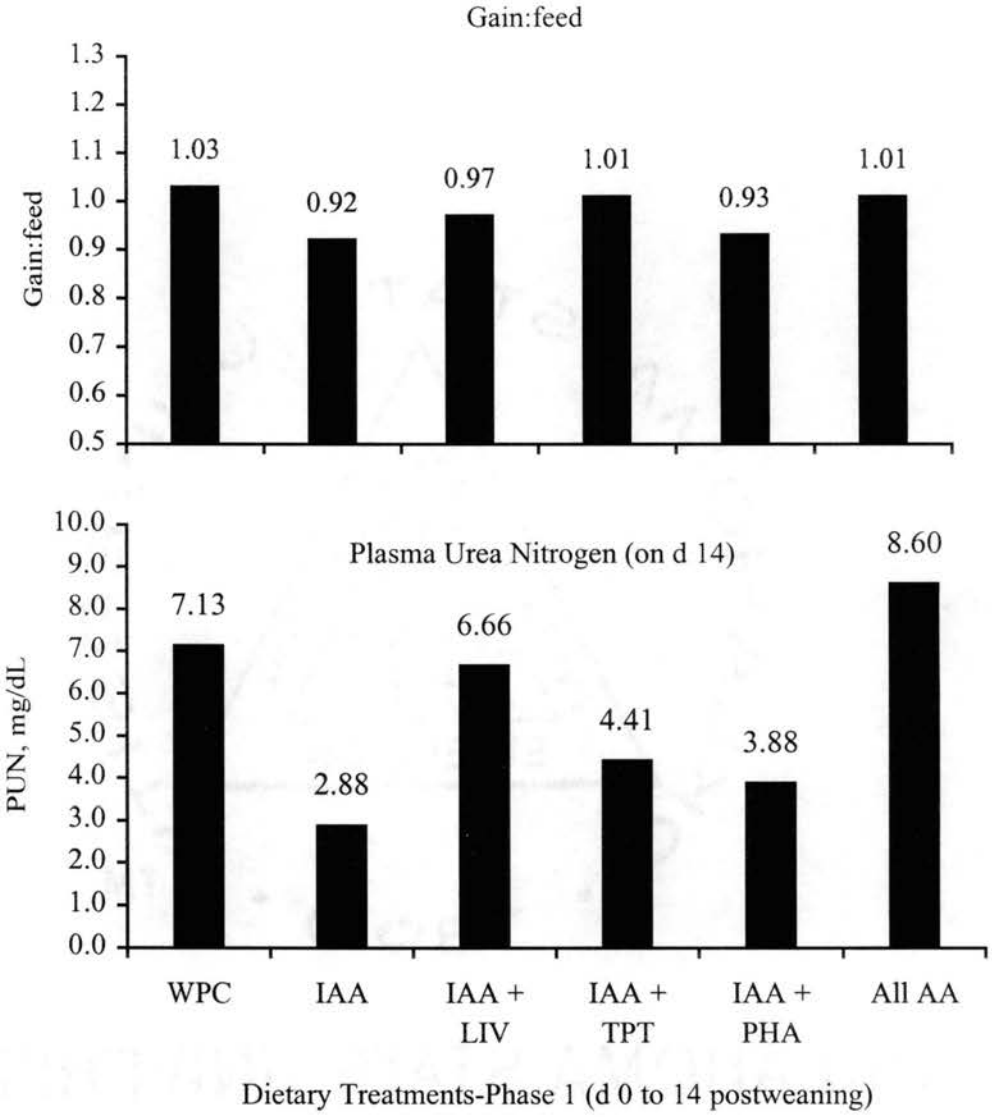

Figure 5.2 Gain:feed (Top panel) and plasma urea nitrogen (Bottom panel) of pigs fed six dietary treatments in Exp. 1. WPC = Basal + whey protein concentrate; IAA = Basal + synthetic essential AA + nonessential AA; IAA + LIV = as IAA + Leu + Val; IAA + TPT = as IAA + Trp + Phe + Tyr; IAA + PHA = as IAA + Pro + His + Arg; All AA = as IAA + LIV + TPT + PHA.

Table 5.5. Composition of experimental diets (Phase 1-Exp. 2).

	Diet[a]				
	1	2	3	4	5
	AA Source				
Ingredient, %	WPC	IAA	IAA + NEAA	IAA + NEAA + T, P, T	IAA + NEAA + P, H, A
Fixed ingredients[b]	77.45	77.45	77.45	77.45	77.45
Lactose	3.29	4.65	4.65	4.65	4.65
WPC, 77%	9.60	-	-	-	-
$Ca_2H_2(PO_4)_2$	1.04	1.40	1.40	1.40	1.40
Limestone	.04	.06	.06	.06	.06
L-Lysine HCl	-	.54	.54	.54	.54
DL-Methionine	.08	.34	.34	.34	.34
L-Threonine	-	.29	.29	.29	.29
L-Tryptophan	-	.10	.10	.10	.10
L-Valine	-	.14	.14	.14	.14
L-Isoleucine	-	.30	.30	.30	.30
Glycine	-		1.08	1.08	1.08
Aspartic acid	-		1.08	1.08	1.08
Glutamic acid	-		1.08	1.08	1.08
Phenylalanine	-	-	-	.135	-
Tyrosine	-	-	-	.135	-
Tryptophan	-	-	-	.040	-
Proline	-	-	-	-	.30
Histidine	-	-	-	-	.15
Arginine	-	-	-	-	.13
Other[c]	4.38	3.53	4.08	4.38	4.28
Sucrose	2.06	5.60	3.612	2.58	2.88
Corn starch	2.06	5.60	3.614	2.58	2.88
$KHCO_3$[d]	-	-	.19	.19	.19

[a] WPC, Basal + whey protein concentrate (Control); Diet 2, Basal + synthetic essential AAs; Diet 3, as Diet 2 + Gly + Glu + Asp + electrolyte; Diet 4, as Diet 3 + Trp + Phe + Tyr; Diet 5, as Diet 3 + Pro + His + Arg.

[b] Contained 33.08% corn, 20% dried whey, 10% dehulled oats, 6.57% menhaden fish meal, 3.5% spray dried plasma protein (APC 920), 2.81% soy protein concentrate, and 1.50% spray dried blood meal (APC 301G).

[c] Contained .10% flavor, .03% ethoxyquin, 2.15-3.00% soybean oil, .20% salt, .30% OSU trace mineral and vitamin premix, .30% zinc oxide, and 1.00% neo-terramycin.

[d] Added to approximate (Na+K)-Cl balance in control diet.

Table 5.6. Chemical composition of diets (Phase 1-Exp. 2).

	Diet [a]				
	1	2	3	4	5
	AA Source				
Ingredient	WPC	IAA	IAA + NEAA	IAA + NEAA + T, P, T	IAA + NEAA + P, H, A
ME, kcal/kg	3308	3308	3308	3310	3310
CP, %	24.51	18.44	21.19	21.83	21.41
Total AA, %					
Lysine	1.65	1.62	1.62	1.62	1.62
Threonine	1.20	1.10	1.10	1.10	1.10
Methionine	.51	.65	.65	.65	.65
Cystine	.51	.33	.33	.33	.33
Met. + Cys.	1.01	.98	.98	.98	.98
Tryptophan	.35	.29	.29	.33	.29
EAA:CP	.52	.59	.52	.52	.52
Digestible AA, %					
Lysine	1.44	1.44	1.44	1.44	1.44
Threonine	.96	.93	.93	.93	.93
Methionine	.44	.60	.60	.60	.60
Tryptophan	.30	.26	.26	.30	.26
AA ratios (% of digestible lysine)					
Lysine	100	100	100	100	100
Threonine	66	65	65	65	65
Methionine	31	42	42	42	42
Met. + Cys.	60	60	60	60	60
Tryptophan	21	18	18	21	18
Isoleucine	62	60	60	60	60
Leucine	145	104	104	104	104
Valine	81	68	68	68	68
Histidine	43	33	33	33	43
Arginine	68	58	58	58	68
Phe. + Tyr.	112	93	93	112	93
Ca, %	.91	.91	.91	.91	.91
P, %	.80	.80	.80	.80	.80

[a] WPC, Basal + whey protein concentrate (Control); Diet 2, Basal + synthetic essential AAs; Diet 3, as Diet 2 + Gly + Glu + Asp (NEAA) + electrolyte; Diet 4, as Diet 3 + Trp + Phe + Tyr; Diet 5, as Diet 3 + Pro + His + Arg.

Table 5.7. The effects of crystalline amino acid additions to low-crude protein diets for weanling pigs (Exp. 2)[a].

	Diet[b]					
	1	2	3	4	5	
	AA Source					
Item	WPC	IAA	IAA + NEAA	IAA + NEAA + T, P, T	IAA + NEAA + P, H, A	SEM
Day 0 to 7						
ADG, g	334[c]	280[d]	258[d]	281[d]	282[d]	11.60
ADFI, g	293[gh]	302[g]	281[gh]	271[h]	279[gh]	11.49
Gain:feed	1.13[c]	.92[d]	.91[d]	1.02[e]	1.00[e]	.019
Day 7 to 14						
ADG, g	322[c]	282[cd]	261[d]	248[d]	250[d]	12.67
ADFI, g	397[i]	397[i]	368[ij]	343[j]	343[j]	15.13
Gain:feed	.81[g]	.71[gh]	.71[gh]	.70[h]	.73[gh]	.072
Day 0 to 14						
ADG, g	328[c]	281[d]	259[d]	265[d]	266[d]	8.28
ADFI, g	345[ij]	350[i]	324[ijk]	307[k]	311[ik]	11.28
Gain:feed	.95[c]	.81[d]	.80[d]	.86[cd]	.85[cd]	.032
Day 14 to 28						
ADG, g	501[gh]	525[g]	488[gh]	469[h]	492[gh]	20.53
ADFI, g	721[g]	698[gh]	686[h]	666[gh]	673[gh]	21.06
Gain:feed	.69[i]	.75[j]	.71[ij]	.70[ij]	.73[ij]	.037
Day 28 to 42						
ADG, g	549	525	497	518	497	20.79
ADFI, g	957	896	908	943	888	31.76
Gain:feed	.57[ij]	.59[i]	.55[j]	.55[j]	.56[ij]	.037
Day 0 to 42						
ADG, g	459[c]	444[cd]	415[d]	417[cd]	418[cd]	9.94
ADFI, g	674[g]	648[gh]	640[gh]	639[gh]	624[h]	16.53
Gain:feed	.68[ij]	.69[i]	.65[k]	.65[ik]	.67[ijk]	.022
PUN, mg/dL						
Day 14	7.94[c]	1.18[d]	4.32[e]	6.18[cf]	6.45[cf]	.409

[a] Least square means for 4 pens (6 pigs/pen) per treatment. Pigs averaged 6.64 and 24.73 kg, respectively at trial initiation and termination, respectively.

[b] WPC, Basal + whey protein concentrate (Control); Diet 2, Basal + synthetic essential AAs; Diet 3, as Diet 2 + Gly + Glu + Asp (NEAA) + electrolyte; Diet 4, as Diet 3 + Trp + Phe +Tyr; Diet 5, as Diet 3 + Pro + His + Arg.

[c,d,e,f] Means within same row with different superscripts differ (P<.01).

[g,h] Means within same row with different superscript differ (P<.10).

[i,j,k] Means within same row with different superscript differ (P<.05).

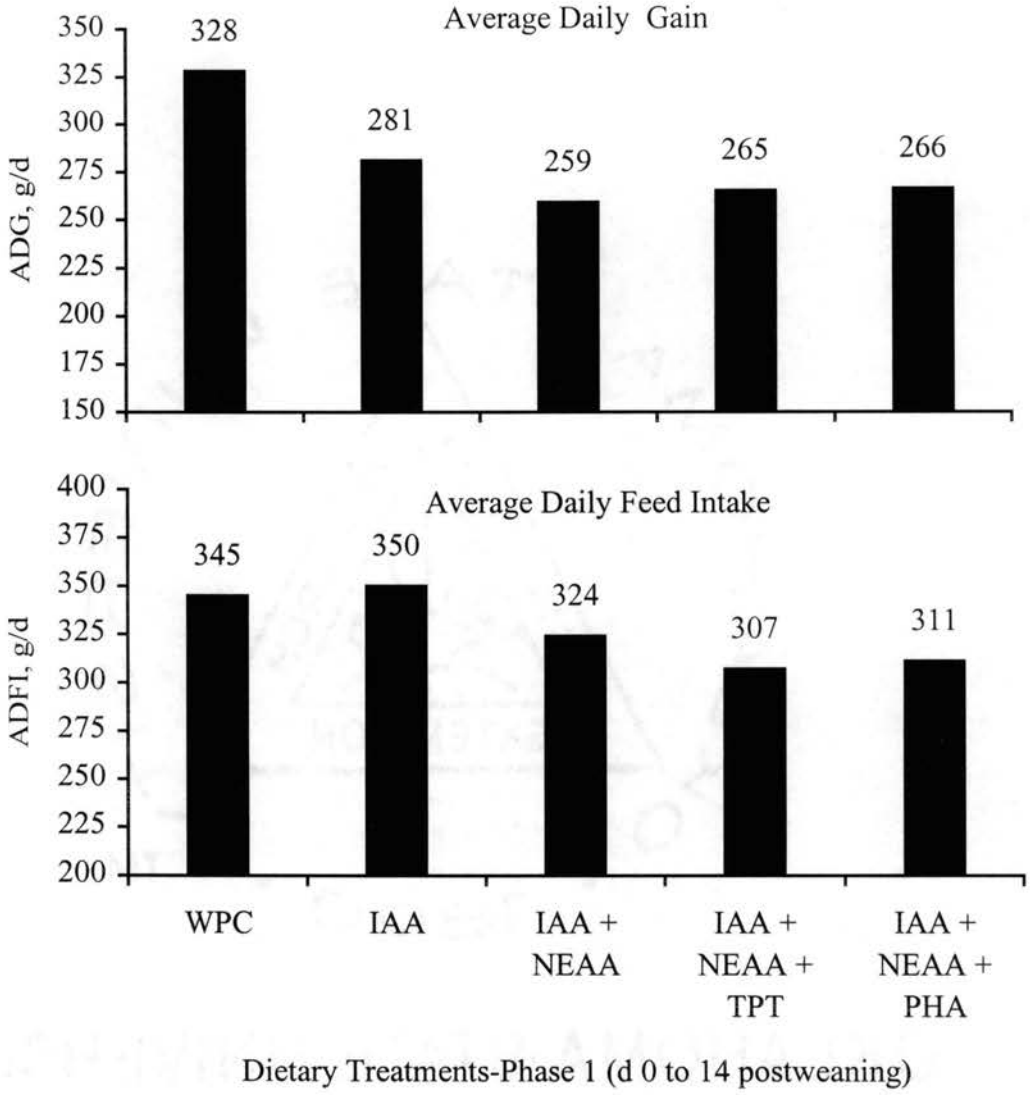

Figure 5.3 Average daily gain (Top panel) and average daily feed intake (Bottom panel) of pigs fed five dietary treatments in Exp. 2. WPC = Basal + whey protein concentrate; IAA = Basal + synthetic essential AA; IAA + NEAA = as IAA + Gly + Glu + Asp + electrolyte; IAA + NEAA +TPT = as IAA + NEAA + Trp + Phe + Tyr + electrolyte; IAA + NEAA + HAP = as IAA + NEAA + His + Arg + Pro + electrolyte.

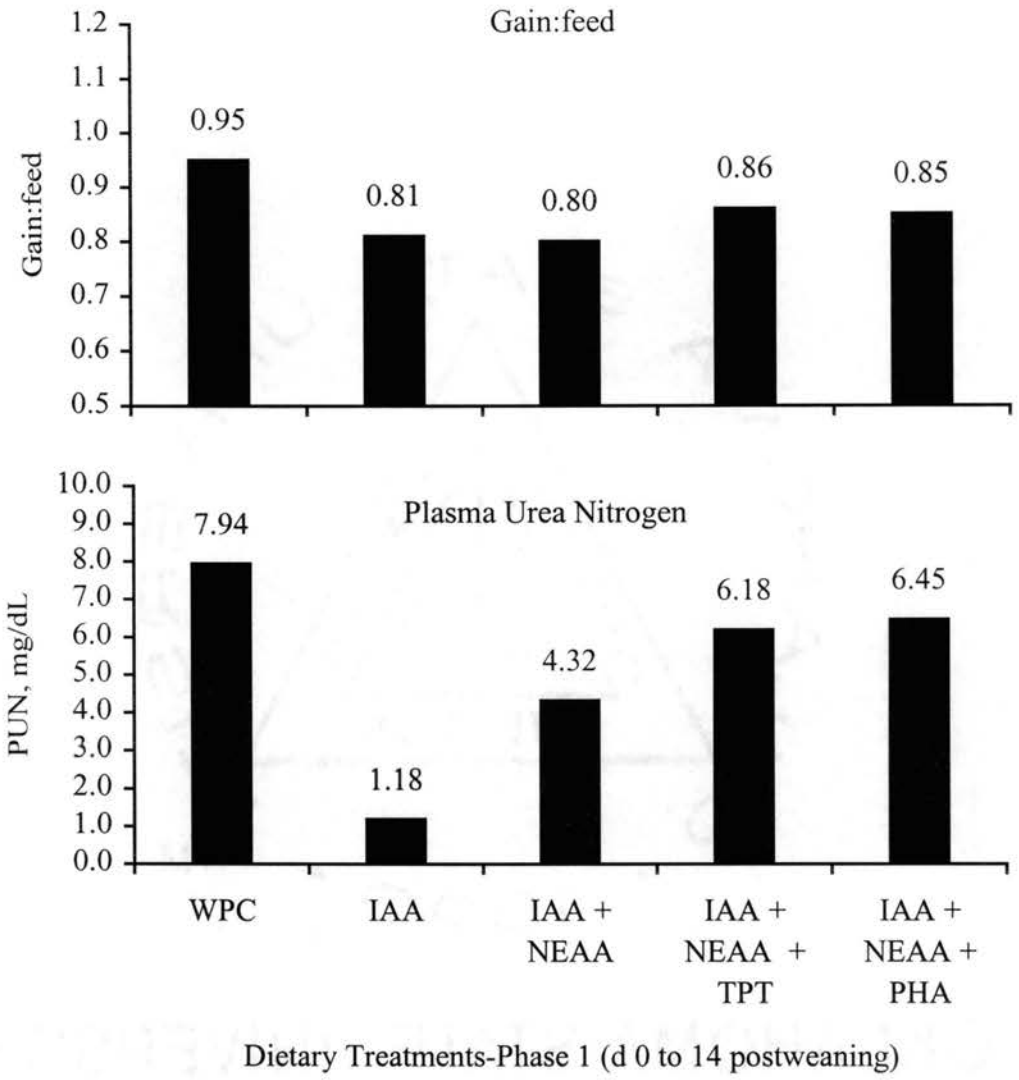

Figure 5.4 Gain:feed (Top panel) and plasma urea nitrogen (Bottom panel) of pigs fed five dietary treatments in Exp. 2. WPC = Basal + whey protein concentrate; IAA = Basal + synthetic essential AA; CAA + NEAA = as IAA + Gly + Glu + Asp + electrolyte; IAA + NEAA +TPT = as IAA + NEAA + Trp + Phe + Tyr + electrolyte; IAA + NEAA + HAP = as IAA + NEAA + His + Arg + Pro + electrolyte.

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CHAPTER VI

SUMMARY

Five experiments were designed to determine the lysine requirement and potential of crystalline amino acid substitution for natural amino acid sources on weanling pig performance. Experiments 1 and 2 were conducted to determine the dietary lysine requirement for segregated early-weaned pigs fed a high nutrient dense diet using whey protein concentrate (77% CP) as a primary source of amino acids. In Experiment 1, 60 pigs (14±2 d of age and 4.2 kg initial BW) penned in groups of three (5 pens/treatment) were used to evaluate four dietary lysine levels (1.30, 1.45, 1.60, and 1.75%). In Experiment 2, 80 pigs (14±2 d of age and 4.5 kg initial BW) penned in groups of four (4 pens/treatment) were used to evaluate five dietary lysine levels (1.30, 1.45, 1.60, 1.75, and 1.90%). In Experiment 1, from d 0 to 7 and 0 to 14 postweaning, average daily gain and gain:feed were increased linearly as dietary lysine level increased and were maximized at 1.75% dietary lysine. In Experiment 2, in the same period, average daily gain and gain:feed increased linearly with increasing dietary lysine level and were maximized at 1.90% dietary lysine. Concentrations of plasma urea nitrogen increased linearly with increasing dietary lysine. These results suggest that segregated early-weaned pigs require at least 1.75% of total dietary lysine to optimize growth performance from d 0 to 14 postweaning (Phase 1).

In Experiment 3, a total of 80 pigs (14±2 d of age and 4.7 kg initial BW) were used to evaluate the efficacy of whey protein concentrate (77% CP) or a mixture of crystalline amino acids at two lysine (1.40 and 1.60% digestible lysine) levels on growth performance and plasma urea nitrogen of segregated early-weaned pigs. Pigs were housed in an off-site nursery with four pigs per pen and four pens per treatment and were assigned to five dietary treatments arranged as a 2x2 factorial with a negative control (1.12% digestible lysine and no whey protein concentrate). The factorially arranged treatments consisted of two lysine levels (1.40% and 1.68% digestible lysine) with whey protein concentrate as a natural intact source of amino acids or the whey protein concentrate component replaced by an ideal mixture of crystalline amino acids. From d 0 to 14 postweaning, pigs fed the negative control diet had lower average daily gain and gain:feed than those fed the whey protein concentrate or crystalline amino acids diets. Pigs fed the whey protein concentrate diets grew faster than pigs fed the crystalline amino acids diets. Gain:feed (G:F) increased with increasing lysine level in the whey protein concentrate diets and decreased with increasing lysine level in the crystalline amino acids diets. For the entire 42-d experiment, pigs fed the whey protein concentrate diets grew faster and were more efficient than pigs consuming the negative control diet during Phase 1. In addition, pigs fed the whey protein concentrate diets were more efficient than pigs fed the crystalline amino acids diets. Pigs fed the negative control diet had lower plasma urea nitrogen concentrations than those fed the whey protein concentrate diets and higher plasma urea nitrogen concentrations than those fed the crystalline amino acids diets. There was an increase in plasma urea nitrogen concentrations (on d 14) with increasing

lysine levels in the whey protein concentrate diets, but a decrease in plasma urea nitrogen concentrations with increasing lysine levels in the crystalline amino acids diets. These data indicate that adding crystalline amino acids to the diet of segregated early-weaned pigs improved performance when compared with pigs fed a low-protein negative control diet, but did not produce equivalent performance when compared with pigs fed the whey protein concentrate diets.

Experiments 4 and 5 were conducted to determine the efficacy of replacing whey protein concentrate (77% CP) with crystalline amino acids on growth performance and plasma urea nitrogen. In Experiment 4, 84 pigs (20-d old, 5.5 kg initial BW) were allotted to 24 pens (3 to 4 pigs/pen; 4 replicates/treatment) based on initial body weight, litter, and sex. The control diet (1.65% lysine) contained 9.6% whey protein concentrate. In Diet 2, whey protein concentrate was replaced with an ideal mixture of essential crystalline amino acids (Lys, Met, Thr, Trp, Ile, and Val). Diets 3-6 were: (3) as Diet 2 + Leu, Ile, Val (LIV); (4) as Diet 2 + Trp, Phe, Tyr (TPT); (5) as Diet 2 + Pro, His, Arg (PHA); and (6) as Diet 2 + crystalline amino acids added to Diets 3, 4, 5 (i.e., LIV + TPT + PHA). From d 0 to 14 postweaning (Phase 1), average daily gain and gain:feed in pigs fed the control diet were greater than those of pigs fed Diet 2. Addition of crystalline amino acids to Diet 2 tended to improve average daily gain and gain:feed with the greatest improvement from the addition of Trp, Phe, and Tyr (TPT). On d 14, plasma urea nitrogen was markedly lower in pigs fed Diet 2 as compared with pigs fed the control diet. In general, addition of crystalline amino acids to Diet 2 increased plasma urea nitrogen with the greatest increase from the addition of Leu, Ile, and Val (LIV).

In Experiment 5, 120 pigs (21-d old, 6.6 kg initial BW) were allotted 20 pens (6 pigs/pen; 5 replicates/treatment) based on initial body weight, litter, and sex. The control diet (1.65% lysine) contained 9.6% whey protein concentrate. In Diet 2, whey protein concentrate was replaced with an ideal mixture of essential crystalline amino acids. Diets 3 to 5 were: (3) as Diet 2 + Gly, Glu, Asp (NEAA) + $KHCO_3$; (4) as Diet 3 + Trp, Phe, Tyr (TPT); and as Diet 3 + Pro, His, Arg (PHA). From d 0 to 14 postweaning (Phase 1), pigs fed the control diet grew faster and were more efficient than pigs fed Diet 2. Addition of Gly, Glu, and Asp (NEAA), Trp, Phe, and Tyr (TPT), or Pro, His, and Arg (PHA) to Diet 2 did not affect growth performance. On d 14, plasma urea nitrogen was markedly lower for pigs fed Diet 2 as compared with pigs fed the control diet. Addition of Gly, Glu, and Asp (NEAA) to Diet 2 increased plasma urea nitrogen but the greatest increase in plasma urea nitrogen was observed with addition of either Trp, Phe, and Tyr (TPT) or Pro, His, and Arg (PHA) to Diet 3. These results suggest that replacement of whey protein concentrate with an ideal blend of crystalline amino acids reduced pig performance during Phase 1 of the nursery period.

In conclusion, the diets for segregated early-weaned pigs (14±2 d of age and less than 5kg initial BW) need to be formulated to contain at least 1.75% total dietary lysine to optimize growth performance from d 0 to 14 postweaning (Phase 1). Substitution of whey protein concentrate (77% CP) with an ideal mixture of crystalline amino acids during Phase 1 reduced growth performance. Furthermore, specific additions of essential and non-essential crystalline amino acids to a diet containing an ideal blend of amino

acids resulted in poorer growth performance when compared with a diet containing natural sources of amino acid (i.e., whey protein concentrate, 77% CP).

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Thesis: ESTIMATION OF THE LYSINE REQUIREMENT OF WEANLING PIGS AND THE POTENTIAL FOR CRYSTALLINE AMINO ACID SUBSTITUTIONS FOR NATURAL AMINO ACID SOURCES

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