EFFECT OF PROTEIN SOURCE ON PERFORMANCE AND AMINO ACID AVAILABILITY IN EARLY WAENED PIGS

BY

KWANG SOU SOHN

Bachelor of Science
Yeung Nam University
Kyung San, Korea
1978

Master of Science
Seoul National University
Seoul, Korea
1983

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirement for
the degree of
DOCTOR OF PHILOSOPHY
May, 1990

EFFECT OF PROTEIN SOURCE ON PERFORMANCE
AND AMINO ACID AVAILABILITY
IN EARLY WEANED PIGS

Thesis Approved:

Charles V Maxwell
Thesis Adviser

Robert Teeter

David S Buchanan

Eldon C Nelson

Norman N. Durham
Dean of the Graduate College

ACKNOWLEDGEMENTS

I wish to express my deepest appreciation to Dr. C. V. Maxwell for his invaluable assistance through the course of my graduate study. I would also like to thank Dr. D. S. Buchanan, Dr. R. G. Teeter and Dr. E. C. Nelson for their continuing interest and encouragement on my committee and their helpful ideas and suggestions provided.

Special thanks are extended to my parents, Mr. and Mrs. Sun Chool Sohn, and my wife's parents, Mr. and Mrs. Yong Whan Choi, for their unending encouragement, support and prayer.

Finally, to my wife, In Sook Sohn, for her support and understanding as well as my lovely daughters, Bonnie and Linda, for their patience during my years as a graduate student at Oklahoma State University.

TABLE OF CONTENTS

Chapter		Page
I.	INTRODUCTION	1
II.	REVIEW OF THE LITERATURE	5
	Performance of Early Weaned Pig Fed Milk and Soybean Proteins	5
	Availability and Balance of Amino Acids	10
	Technology of Treatment of Soybean Protein	18
	Morphological Development of the Small Intestine	21
	Antigenicity of Soybean Protein	26
	Lactose and Protein Utilization	31
	Differences Between Ileal and Fecal Digestibility Values	35
	Antinutritional Factors in Soybeans	39
III.	EFFECT OF SOURCE OF DIETARY PROTEIN ON PERFORMANCE OF EARLY WEANED PIGS	45
	Summary	45
	Introduction	47
	Materials and Methods	49
	Results and Discussion	53
IV.	AMINO ACID AVAILABILITY OF VARIOUS PROTEIN SOURCES IN EARLY WEANED PIGS	98
	Summary	98
	Introduction	99
	Materials and Methods	102
	Results and Discussion	104
LITERATURE CITED		123

LIST OF TABLES

Table Page

CHAPTER III

3.1. Composition of Experimental Diets Fed During Period 1 (2WK) 68

3.2. Nutrient Composition of Diets Fed During Period 1 (2WK) 70

3.3. Protein and Amino Acid Composition of Dietery Protein Sources 71

3.4. Protein and Amino Acid Composition of Experimental Diets 73

3.5. Trypsin Inhibitor Activity of Protein Sources and Diets 77

3.6. Mineral Analysis and Physical Properties of Protein Sources 78

3.7. Composition of Experimental Diets Fed During Period 2 79

3.8. Typical Composition of Soybeans and Soybean Products 80

3.9. The Effect of Protein Source on ADG in Period 1 81

3.10. The Effect of Protein Source on ADG in Period 2 82

3.11. The Effect of Protein Source on Feed Efficiency (G:F) 83

3.12. The Effect of Protein Source on Feed Intake During Period 1 84

3.13. The Effect of Protein Source on Feed Intake During Period 2 85

3.14. The Effect of Protein Source on Pig Weight 86

Table		Page
3.15.	The Effect of Protein Source on Average Daily Gain (ADG) and Average Daily Feed Intake (ADFI) Overall Period (5 WK)	87
3.16.	Apparent Availability of Dry Matter and Ash Measured Over the Total Digestive Tract for Early Weaned Pigs at Week One After Weaning	89
3.17.	Apparent Availability of Dry Matter and Ash Measured Over the Total Digestive Tract Early Weaned Pigs at Week Two After Weaning	90
3.18.	Difference Between Period (Week Two VS Week One) in Nutrient Availability Estimates Determined Over the Total Digestive Tract ...	91
3.19.	Apparent Availability of Nitrogen and Amino Acids Measured Over the Total Digestive Tract for 28 Day Old Pigs	92
3.20.	Apparent Availability of Nitrogen and Amino Acids Measured Over the Total Digestive Tract for 35 Day Old Pigs	94
3.21.	Difference of Apparent Fecal Amino Acid Availability Estimates Between 2 Periods (Week Two VS Week One) in Early Weaned Pigs	96
	CHAPTER IV	
4.1.	Composition of Experimental Diets	113
4.2.	Nutrient Composition of Diets	114
4.3.	Protein and Amino Acid Composition of Dietary Protein Sources	115
4.4.	Protein and Amino Acid Composition of Diets ...	116
4.5.	Apparent Availabilities of Dry Matter and Ash at the End of the Small Intestine and Over the Total Tract of Early Weaned Pigs ...	117
4.6.	Apparent Ileal Availability of Nitrogen and Amino Acids in Milk and Soybean Protein Sources in Early Weaned Pigs	118

Table		Page

4.7. Apparent Fecal Availability of Nitrogen and Amino Acids in Milk and Soybean Protein Sources in Early Weaned Pigs 119

4.8. Difference Between Apparent Fecal Availability Estimates and Those Determined at the End of the Small Intestine in Early Weaned Pigs ... 120

4.9. The Effect of Time on Apparent Ileal Amino Acid Availability in Early Weaned Pigs 121

4.10. The Effect of Time on Apparent Fecal Amino Acid Availability in Early Weaned Pigs 122

LIST OF FIGURES

Figure | Page

CHAPTER III

1. Outline of Process for the Production of Isolated Soy Protein 75

2. Processes for Preparing Soy Protein Concentrates 76

3. LS Means of Pig Weight by Week 88

CHAPTER I

INTRODUCTION

Early weaning of pigs as early as three weeks is commonly followed by a check in growth rate and feed intake and frequently by diarrhea even though early weaning is considered essential in order to shorten the breeding cycle and maximize reproductive efficiency of the sow herd.

It is also common to observe a longer postweaning growth depression and a higher incidence of mortality in early weaned pigs when compared to those weaned at an older age. Virtually all swine herds experience this postweaning lag in performance, which has been traced to a number of possible causes including poor environmental conditions, nutritional changes and physical and social stresses. These problems occur when the passive immunities acquired from the sow's colostrum are declining and the pig's own immune system is not fully mature, thereby leading to the rapid onset of diarrhea or other diseases. Some of the problems associated with early weaning could arise from the failure of a relatively immature gut to adapt efficiently to sudden changes in diet.

It has been very well documented that growth rate and efficiency of feed utilization of early weaned pigs are much better with milk protein than with soybean protein. And also, milk protein has been used in the prestarter diet to minimize the effect of the postweaning lag period which lasts from five to ten days, and is characrerized by low feed intake, little or no gain and frequently by diarrhea. Milk proteins, however, are expensive relative to soybean proteins and from an economic standpoint, the utilization of milk protein in starter diets may not be practical.

The reasons for the unfavorable response to soybean protein have not been clearly determined in the early weaned pig but possible explanations are as follows: 1) Antinutritional factor(s) present in soybean protein; 2) A reduction in proteolytic activity probably contributes to the poor digestibility of soybean proteins; 3) Amino acid availability in soybean protein is lower than in milk protein in the young pig; 4) Soybean proteins(glycinin and beta-conglycinin) frequently induce an allergic reaction; 5) Soybean proteins may induce morphological changes in the small intestine and 6) Soybean proteins may cause change of intestinal environment such as pH and flow rate of digesta. Possible cause of changes in the piglet small intestine in response to protein source has not been sufficiently tested in the early weaned pig.

Due to the high cost of milk proteins, soybean flakes have been supplemented with essential amino acids and/or digestive enzymes as well as treated with alkali or acid to improve performance and efficiency of utilization.

Swine producers are currently replacing the more standard corn-soybean diets for early weaned pigs with diets containing very high levels of milk proteins, glucose and lactose as a carbohydrate source and a high level of vegetable fat as a fat source although these diets are expensive and have not been tested sufficiently. The ability to utilize the soybean protein from soy protein concentrate or isolated soy protein could be a means of reducing the inclusion rate of more expensive milk proteins in the diet of early weaned pigs and also it is essential to delineate factors responsible for the poor performance of young pigs fed soybean protein.

Recently, two studies (Dietz et l., 1988; Guerin et al., 1988) indicate that some sources of refined soy ptotein will support performance similar to that observed in pigs fed milk protein.

This study was conducted to compare the performance of early weaned pigs fed an all milk based diet using dried skim milk as the primary source of lysine with soybean protein sources. Soybean proteins differing in the composition of both protein and non-protein components were utilized. Two isolated soy proteins(91.5% CP), three soy protein concentrates(65.5% CP) and 50% soybean meal were used to evaluate the effect of complete replacement of the dried skim milk protein. The specific objectives were to : 1) further evaluate the gain and efficiency of gain differences from diets containing milk or soybean protein sources in early weaned pigs; 2) compare the effect of isolated soybean protein with that of soybean protein concentrates on the performance of young pigs; 3) determine the ileal amino acid availability of milk and soybean protein in ileally cannulated early weaned pig; 4) compare differences between ileal and fecal amino acid digestibility values; and 5) relate nutrient availability of early weaned pigs to performance estimates obtained in the growth study (objective 1).

CHAPTER II

REVIEW OF LITERATURE

Performance of Early Weaned Pig Fed Milk and Soybean Proteins

Artificial rearing of pigs from 2 days of age has been successful using a liquid milk diet (Braude et al., 1970). However, it has been demonstrated (Wilson and Leibholz., 1979) that growth rates of 250 g/ day can be achieved by pigs from 7-28 days of age when fed dry pelleted diets in which the source of dietary protein was milk. Several workers have reported an average daily gain in excess of 180 g during the first 2 wk of artificial rearing of pigs when the dietary protein source was entirely of milk origin (Sewell et al., 1953; Schneider and Sarrett, 1969; Coalson and lecce, 1973; Pettigrew et al., 1977).

A large number of studies have been conducted to compare performance of early weaned pigs fed diets containing either milk or soybean protein sources (Bayley and Holmes, 1972; Combs et al., 1963; Kellogg et al., 1964; Leibholz, 1982; Maner et al., 1961; Mateo and Veum, 1980; Partridge, 1981; Schmidt et al., 1973; Sherry et al., 1978; Veum et al., 1986; Walker et al., 1986; Wilson and Leibholz, 1981a,b,c,d). These studies indicate a reduction in ADG associated with the replacement of dietary milk proteins with various sources of soybean protein.

For pigs weaned between 15 and 28 days of age, those fed milk proteins had an improved average daily gain ranging from 0 to .17 kg with a weighted mean average daily gain of .06 kg greater than pigs fed a source of soybean protein. In addition, there was an increase in average daily feed intake ranging from .03 to .20 kg with a weighted average of .07 kg and the F:G was decreased by a weighted average of .21 kg with a range of .02 to .48 kg.

Wilson and Leibholz (1981a) suggested that soybean proteins as the only dietary protein source do not support similar performances for pigs up to 4 weeks of age as compared to those given diets containing milk protein. Similar conclusions have been reached by numerous workers using isolated soy protein (Hays et al., 1959; Maner et al., 1961), soybean flour (Bayley and Holmes, 1972) or soybean meal (Hays et al., 1959). The effect of substituting soybean meal for milk protein in diets for young pigs resulted in a linear decrease in growth rates. Sherry et al (1978) have also shown that daily gains and feed efficiencies decreased as the amount of milk protein in the diet decreased for pigs from 2-23 days of age, but Zamora et al (1975) concluded that soybean meal could be a major source of protein for artificially reared pigs. However, their diets containing soybean meal contained 260 g crude protein/kg while the crude protein content of their milk diet was only 240 g/ kg. Also, the weight gains of pigs in the study of Zamora et al (1975) ranged from 100-150 g/ day which is approximately half the weight gains obtained in the experiment of Wilson and Leibholz (1981c). With pigs from 21-36 days of age, Jones et al (1977) found that soybean flour as a source of protein was equivalent to milk, but pigs of less than 18 days of age were not able to utilize soybean flour efficiently.

In addition to the pronounced performance differences noted between young pigs fed either milk or soybean protein sources, metabolic differences have also been observed including differences in gastric pH, rate of passage, apparent nutrient digestibility and plasma urea concentrations. Wilson and Leibholz (1980c) suggested that the apparent digestibility of nitrogen of two isolated soy proteins were 94.5 and 91.6%. A small improvement in the apparent digestibility of dry matter and nitrogen with increasing age of the pigs from 10-24 d when diets containing soybean proteins were fed confirms the observations of Hays et al (1959), but the apparent digestibility of dry matter and nitrogen did not improve with increasing age of pigs given milk diets. Nitrogen retention as a proportion of dietary nitrogen intake was greater and plasma urea concentration was lower for pigs fed milk protein diets when compared to those fed soybean protein diets. This supports the conclusion of Eggum (1970) that the level of blood urea is inversely proportional to the efficiency of nitrogen utilization. Similar results were obtained by Hay et al (1959) who showed that the nitrogen retention in pigs at 2 weeks of age was greater when they were fed diets containing milk protein than when they were fed diets containing soybean meal (76 vs 51%) although by 5 weeks of age nitrogen retention had decreased in pigs fed the milk diets and remained at a similar level as observed in pigs fed the soybean meal diets.

In a study, involving pigs equipped with gastric fistulas, Maner et al. (1962) found that the stomach pH of 4 wk old pigs fed liquid casein diets increased from pH 1.8 to pH 5.6 at 5 minutes after feeding and dropped to a prefeeding level of pH 1.7 two hours after feeding, whereas four hours were required for the pH to return to prefeeding levels (pH 1.8) in pigs fed soybean protein diets. However, in 8 wk old pigs the pH of stomach contents returned to prefeeding levels within 2 h with both casein and soybean protein diets. Newport and Keal (1982) reported that substitution of soybean protein for milk protein did not significantly ($p > .05$) affect the total amount or the pH value of digesta remaining in the stomach 1 h after feeding and there were no significant difference in stomach pH values. Wilson and Leibholz (1981b) reported that there was no change in gastric pH with age of pigs from 14-35 d of age which supports the findings of Decuypere et al. (1978), who found no pH alterations with suckling or early weaned pigs during the first 4 weeks of life. pH values along the intestine did not differ with source of dietary protein and were similar to values obtained by other workers using young pigs (Smith and Jones, 1963; Hamilton and Roe, 1977). As also shown by these latter workers, pH values showed a gradual increase from the duodenum to the ileum.

Maner et al. (1962) suggested that the rate of passage through the gastrointestinal tract of 4 wk old pigs was 14 to 24 h for pigs fed semipurified soybean protein diets compared to 36 to 48 h in those fed casein diets. Rate of passage was similar for both diets in 8 wk old pigs and ranged from 40 to 50 h. Casein also produced a faster postprandial decrease in pH of gastric contents with a slower rate of passage through the intestinal tract of the young pig than isolated soy protein. The buffering action of isolated soybean protein delays the activation of pepsinogen in the stomach thereby reducing the efficiency of protein digestion.

In contrast to the previous studies, Decuypere et al. (1981) reported that average daily gain and feed efficiency of pigs fed milk based diets in which 40% of the milk protein was replaced by an isolated soy protein that was totally soluble in water or an isolated soy protein that was easily dispersed in water, was superior to that of pigs fed an all milk protein diet. In their study, in which the effect of replacement of dried skim milk by either a soy protein isolate or concentrate was considered, Newport and Keal (1982) suggested that in the 28 d old pig, soybean protein whether in the form of an isolate or concentrate was digested as well as milk protein as shown by the measurement of apparent digestibility and observations on proteolysis in slaughtered pigs.

Allee and Hsu (1981) also demonstrated that replacing 25% of the milk protein with modified soybean protein resulted in similar weight gain and feed efficiency with a decreased incidence of scours.

Studies by Geurin et al. (1988) indicated that isolated soy protein can be used with whey to replace dried skim milk in a prestarter for baby pigs at 3-6 weeks of age. Giesting et al. (1985) reported that average daily gain of starter pigs fed a milk protein diet with lactose was superior to that of pigs fed an isolated soy protein diet, however the performance was similar among pigs fed milk protein and soy protein concentrate diets. Dietz et al. (1988) indicated that performance was improved in early weaned pigs fed isolated soy protein as a protein source when compared to those fed milk protein or soybean meal as a protein source.

Availability and Balance of Amino Acid

Pigs do not have a requirement for protein, but need an appropriate balance of essential amino acids and a source of amino nitrogen to synthesize non-essential amino acids.

The ARC (1981) proposed that the concept "ideal protein" be used to establish the balance of amino acids required by the pig. The concept assumed that the concentration of amino acids in lean tissue of pigs should indicate the balance of amino acid required in the diet. The ARC (1981) indicated that ideal protein should contain 7 % lysine within the protein and derived a balance of amino acids relative to lysine.

Since lysine is normally the first limiting amino acids, ARC (1981) proposed that the ideal balance should be set relative to lysine. It is therefore necessary to understand the factors affecting the lysine dose-response before considering formulation of diets to ideal protein. The primary factors influencing the pig's requirement for lysine are genotype, sex, liveweight, energy intake and environmental factors.

Requirements for additional amino acids can be met by supplementing the diets with one or more protein-rich ingredients and /or synthetic amino acids.

In order to provide adequate, but not excessive, levels of amino acids to swine, digestible instead of total amino acid supply should be considered. In particular, attention should be paid to amino acids likely to be limiting.

A large number of studies have been conducted to determine amino acid digestibility in growing-finishing swine during the last two decades. However, amino acid availability estimates for supplemental protein sources in the young pig have not been made.

Not all of the amino acids present in feedstuffs are biologically available to the pig. The amino acid availability can be reduced by incomplete digestion and absorption, by the presence of inhibitors of digestive enzymes, or by heat damage. Recent evidence has shown that protein sources vary widely in their ability to supply amino acids in forms suitable for protein synthesis (Sauer et al., 1982). Therefore, in order to improve the accuracy of diet formulation for the pig, some knowledge of the availability of the individual amino acids in the feedstuff is essential.

Protein sources vary in amino acid content and in availability measured at either the ileum or the fecal samples of growing-finishing pigs (Homes et al., 1974; Tanksley and Knabe, 1980; Taverner and Farrell. 1981; Jorgensen et al., 1984). However, studies of availability in pigs weaned at 21 d have not been reported, although the effect of protein source on amino acid availability may explain much of the variability observed in performance.

Walker et al. (1986b) suggested that the apparent ileal availability of the essential amino acid and the nonessential amino acid, with exception of cystine and glycine, was lower in pigs fed soybean meal than in those fed milk, isolated soy protein and a soy protein concentrate.

Wilson and Leibholz (1981d) also observed that the apparent digestibility of amino acid in pigs weaned at 7 days of age was highest in the milk protein, intermediate in the isolated soy protein and lowest in the soybean meal. The apparent digestion of amino acids at the ileum of pigs fed isolated soy protein increased with increasing age of pigs from a mean of 82% at 14 d of age to 87% at 35 d of age. However, the utilization of milk protein diets has been shown not to change with increasing age of pigs (Wilson and Leibholz, 1981c). The apparent digestion of individual amino acids obtained from young pigs fed milk protein diets are very similar to values obtained with older pigs fed a similar diet (Zebrowska, 1973b).

Maner et al. (1961) reported improved nutrient digestibilities when casein was used as the protein source for the baby pig as compared to isolated soy protein. The lower digestibility of isolated soy protein may be due to an inadequate enzyme system of the young pig (Lewis et al., 1957), which lacks proteolytic enzymes. Pecas et al. (1964) suggested that protein and dry matter digestibilities were reduced by the exclusion of pancreatic secretion from the duodenum. However, Pond et al. (1971) concluded that the inferior performance of pigs fed isolated soy protein compared to that of pigs fed casein or fish protein concentrate was not due to an insufficiency of pancreatic chymotrypsin, trypsin, amylase or lipase, but to some other limiting factor(s). Their results indicated that pancreatic exocrine function would not explain the differences in the performance of baby pigs fed diets of different protein composition.

Whether the higher protein digestibility of casein than of isolated soy protein is due to a greater synthesis of proteolytic enzyme in the pancreas of the casein fed pigs or a slower release of pancreatic secretions into the duodenum of the pigs fed isolated soy protein is not clear. Maner et al. (1962) reported a faster postprandial drop in pH of stomach contents and a slower rate of passage of food residues through the gastrointestinal tract of 4 week old pigs fed casein compared to those fed isolated soy protein. The same workers suggested that the buffering action of isolated soy protein would delay the activation of pepsinogen secreted by the chief cells of the gastric glands, thus delaying and reducing the digestion of the protein.

The capacity of the young pig to secrete pepsin and acid is limited at birth and increases with age (Cranwell and Titchen, 1976; Decuypere et al., 1978). Pig pepsinogens are hydrolyzed to pepsin in acid conditions, slowly at pH 4 and rapidly at pH 2. Accordingly, high pH values would allow only limited proteolysis. The amount of true protein-N in the stomach digesta relative to the total N was high indicating that little proteolysis had occurred in the stomach.

Zebrowska (1973c) has shown that in 60 kg live weight pigs approximately 85% of the nitrogen was in the form of peptides and free amino acids in the digesta reaching the duodenum. This would indicate some gasrtic protein hydrolysis in these pigs as would be expected by the lower gastric pH values of adult pigs as shown by Lawrence (1972).

Wilson and Leibholz (1981c) suggested that the pigs fed a milk protein diet had greater endogenous secretion of nitrogen than pigs fed an isolated soy protein or soy protein concentrate diet. However, this could be explained by differences in nitrogen absorption from the duodenum and by the greater nitrogen and dry matter intakes of pigs fed the milk protein diet.

The flow of nitrogen to the ileum was greater in pigs fed the soybean protein diets than the milk protein diets. This may be due both to the greater endogenous nitrogen secretion in the pigs given soybean protein and to the lower absorption of exogenous and endogenous nitrogen before the terminal ileum. Zebrowska (1973b) has shown that amounts of endogenous nitrogen in pigs fed soybean meal were twice that obtained from pigs fed other protein sources.

The proportions of threonine, proline and glycine in the ileal digesta from pigs fed a N-free diet were greater than for pigs fed the protein diets. These amino acids constitute a major fraction of mucoproteins (Horowitz, 1967). Gitler (1964) has demonstrated that threonine, proline and glycine are among the most slowly absorbed amino acids from the intestines of rats. Purser (1976), however, suggests that the high threonine levels observed in ileal digesta are a result of the low affinity of threonine for the transport site. Wilson and Leibholz (1981d) suggested that the net absorption of amino acid measured at the terminal ileum varied between individual amino acids, and with the source of protein fed. Absorption of amino acids to the ileum followed a similar pattern as total nitrogen, being greater for milk protein diets than for the isolated soy protein or soybean meal diets. Low (1979) has also found that pigs absorb amino acids from semi-synthetic casein diets more efficiently than other protein sources.

Utilization of nitrogen by pigs fed soybean protein has been demonstrated to increase with increasing age of pigs, indicating an adaptation to vegetable protein. (Hays et al., 1959; Wilson and Leibholz, 1981a). This is demonstrated from apparent digestion of amino acids measured at the ileum in pigs fed isolated soy protein which increased for pigs from 14-35 days of age (Wilson and Leibholz, 1981c). Also, the values reported by Wilson and Leibholz (1981c) for pigs fed soybean meal is considerably below values obtained with older pigs fed SBM (Holmes et al., 1974).

The apparent ileal digestibility of lysine, methione and threonine, for example, obtained with 45 kg live weight pigs fed soybean meal (Holmes et al., 1974) were 90.7, 96.7 and 82.2% respectively. The amino acids showing the greatest apparent digestion varied with the type of dietary protein. For pigs fed milk and soybean meal protein, methione and lysine had the highest apparent digestibility. For pigs fed isolated soy protein, arginine had the hightest apparent digestibility (Wilson and Leibholz, 1981d).

Methionine and lysine supplementation of the diets resulted in a reduction in the apparent digestibility of other amino acids measured at the ileum. The digestion of nitrogen and dry matter was also depressed. (Wilson and Leibholz, 1981d), and this may be partly attributed to the lower feed intake. It may also be partly due to a competition for absorption sites and perhaps the extent of hydrolysis of the protein sources. Methionine supplementation of the protein sources increased the apparent digestion of methionine (Wilson and Leibholz, 1981d). This is in contrast to the findings of Wapnir et al. (1972) who found that when an amino acid was fed to rats in excess of normal requirements it caused a depression in the subsequent absorption of that amino acid.

A greater absorption of an amino acid has been shown to result following the feeding of a diet low in that amino acid (Nakamura et al., 1972; Wapnir et al., 1974). The true digestibility of methionine to the ileum of pigs fed isolated soy protein was lower than for milk diets (Wilson and Leibholz, 1981d). Isolated soy protein has been shown to be deficient in methionine for young pigs (Maner et al., 1961). The lower digestibility may be attributed to the lower hydrolysis of soybean protein in the small intestine (Wilson and Leibholz, 1981c).

From their results, Wilson and Leibholz (1981d) concluded that the reduced performance of young pigs fed soybean proteins is the result of the lower digestion of amino acids to the ileum as compared with pigs fed milk protein. The apparent digestion of amino acids to the ileum of young pigs given milk protein was similar to that of adult pigs, while the apparent digestion of amino acids to the ileum of pigs given soybean meal was considerably below the values obtained using older pigs.

Technology of Treatment of Soybean Protein

It is of interest to determine if soybean proteins could be improved by processing for young pigs. Alkali treatment of soybean proteins has been shown to result in an improvement of pig performance (Lennon et al., 1971), while variations in the growth rates were observed in turkey poults fed different isolated soy proteins (Vohra and Kratzer, 1967). Colvin and Ramsey (1968) found that acid or alkali treatment of soybean flour produced gains in calves similar to that obtained with a conventional milk replacer. Also, Lennon et al. (1971) showed that alkali treatment of soybean flour and soybean meal fed in liquid diets to young pigs increased weight gains by 54 to 68% and 60 to 77% respectively over that obtained by pigs receiving untreated protein sources. However, Wilson and Leibholz (1981a) found that the alkali treatment of soybean flour did not result in any significant improvement in performance of the pigs over that of pigs receiving untreated soybean flour. In their experiment the pigs were 7 to 28 days of age while those of Lennon et al. (1971) were from 28 to 56 days of age. It has been shown that the pig's ability to utilize soybean protein increases with age from 2 to 5 weeks of age (Hays et al., 1959; Jones et al., 1977). Jones et al. (1977) suggested that growth rates were similar regardless of the source of the protein. The growth rates of pigs fed acid-treated soybean flour were not different from the growth rates of pigs receiving untreated soybean flour. Lennon et al. (1971) also suggested that reducing the buffering capacity of the soy flour with acid did not improve growth.

Exposure of proteins to alkali is increasingly applied in technological treatment of foods and feeds, e.g., for dissolving proteins in the preparation of isolates and concentrates (Sullivan, 1943); for obtaining proteins with specific properties such as foaming, emulsifying or stabilizing (Circle and Johnson, 1958); for destruction of aflatoxin in groundnuts (Screenivasamurthy, 1967); and for obtaining protein solutions suitable for spining fibers (Soy fibers, 1967).

Obviously alkali treatment of food proteins may result in chemical changes. De Groot and Slump (1969) reported that drastic treatment of food proteins with alkali, at pH 12.2 and $40^{0}C$ for 4 hours, may induce chemical changes which are associated with the occurrence of a new amino acid, lysinoalanine which is poorly absorbed, and with decreased contents of cystine and, to a lesser extent, lysine. The amount of lysinolalanine formed in isolated soy protein upon exposure at pH 12.2 increased with rising temperature and a longer exposure period. More drastic treatment at a temperature between 40 and 80^{0}C also destroys serine and arginine. Destruction of cystine and lysine in alkali treated fish meal has been reported (Carpenter et al., 1952).

A primary change in proteins by alkali treatment is supposed to be the formation of dehydroalanine residues from cystine and serine residues (Patchornik and Sokobvsky, 1964). This compound may react with the E-amino group of lysine, which results in the formation of lysinoalanine, or with intact cystine residues, which leads to the formation of new sulfur-containing amino acid (lanthionine).

Destruction of cystine and lysine in proteins often means decreased nutritive value because the majority of food proteins is limited by either the sulfur-containing amino acids or lysine. De Groot and Slump (1969) reported that exposure of isolated soy protein to pH 12.2 was invariably accompanied by a decrease in net protein utilization (NPU). The extent of impairment of protein quality was correlated with the severity of alkali treatment. In contrast, Bressani et al. (1967) did not obtain a significant difference in NPU or PER between isolated soy protein before and after exposure to alkali of pH 12.2 at room temperature for less than 10 minutes.

The method of preparation of ISP may explain the differences in performance obtained by pigs fed two different isolated soy protein as the only source of dietary protein. Alkali treatment is commonly used in the processing of isolated soy proteins (Circle and Smith, 1972) and strong alkali, pH 12.2, has resulted in the formation of lysine and alanine (De Groot and Slump, 1969) which is poorly absorbed. Vohra and Klatzer (1967) obtained differences in growth rates of turkey poults when fed different isolated soy protein. Smith and Sisson (1975) fed isolated soy protein and soy protein concentrates to preruminant calves, and they found that the method of preparation influenced the flow of nitrogen from the abomasum.

The beneficial effect of ethanol extraction of soybean meal used in calf diets in preventing digestive disorders and in improving the growth of calves (Gorrill and Thomas, 1967; Nitsan et al., 1971 and 1972) may have been due in part to the removal of ethanol soluble oligosaccharides. Sucrose, a major disaccharide in soybeans, is not digested by the calf because of the absence of sucrase in the intestine(Siddons, 1968).

Morphological Development of the Small Intestine

Alterations in the small intestinal structure after early weaning has been reported and may be related to subsequent poor performance (Hampson, 1986a; Kenworthy., 1976).

The basic functional unit of the intestine is the crypt-villus unit. The villi and lamina propria play an important role in the digestion and absorption of nutrients and in the immunological protection at the intestinal level. The cell proliferate in the crypt. The entire proliferative cycle of an intestinal crypt cell is about 1 day, and the life-span of a villus cell is about 3 days. Mitosis lasts 1 h and DNA synthesis lasts 12 h. Usually each villus is supplied with cells from about three crypts. At the termination of proliferation in the upper third of the crypt, differentiation is initiated. The cell migrate out of the crypt and on to the villus, and in humans these cells are finally extruded from the tip of the villus 48-72 hours later. Differentiation is distinguished by morphologic and chemical changes. As a result of this process, the epithelial cells of the villus are endowed with the specific functions required for digestion and absorption.

Hampson (1986a) suggested that weaned pigs showed a highly significant increase in crypt depth and an increase in the complexity of villus morphology with a dramatic reduction in villus height when compared to unweaned pigs. The reduction in small intestinal absorptive area and the appearance of a less mature enterocyte population help to explain the increased susceptibility of the pig to diarrhea and growth checks in the post weaning period.

Dietary constituents are important in modifying the developmental pattern of intestinal and pancreatic enzymes. At the time of weaning, the dietary content of fat and lactose falls, and the dietary content of sucrose and starch rises. Thus, weaning is associated with a change from the relatively high fat, low carbohydrate diet of milk, to the relatively low fat, high carbohydrate diet of solid foods. Lactase does not appear to be an adaptive enzyme in man (Knudsen et al., 1968), although feeding lactose increases brush border membrane lactase in rats (Lebenthal et al., 1973). When suckling rats are fed a diet containing cow's milk protein to which has been added lactalbumin and corn oil to approximate the protein and fat concentration of rat milk, the activities of jejunal sucrase and maltase, the relative weight of the intestine, the mitotic index of crypt cells, and the rate of cellular proliferation and migration are all altered to approach that of the adult animal(Herbst and Koldovsky, 1972).

Feeding premature infants a high fat diet has no effect on pancreatic enzymes (Zoppi et al., 1972), but feeding a high protein diet results in higher trypsin and lipase levels in the pancreatic secretions. Feeding a starch diet results in the appearance of a low level of amylase activity. As compared with premature infants fed milk based diet, those infants fed a soybean based diet had a greater pancreatic secretion of trypsin and lipase (Lebenthal et al., 1981).

Seegraber and Morrill (1986) reported that villi were long, tapering and uniform in calves fed milk; however, gradual deterioration in villus integrity was seen in calves fed soybean proteins. Calves fed casein had a greater variation in size and conformation of villi. Calves fed fish protein concentrate performed poorly and had abnormal villi.

The etiology of the structural changes in the small intestine after weaning has not been established. Suggestions as to their causes have included the toxic action of metabolites derived from microbial degradation of digestive products (Kenworthy, 1976), the physiologically damaging effects of fiber in the diet (Tasman-Jones et al., 1982; Moore et al., 1988), the action of rotaviruses (Lecce et al., 1982), the action of enteroglucagon (Hampson, 1986), and more recently intestinal hypersensitivity reactions to dietary antigens (Miller et al., 1984).

Possible cause of changes in the piglet small intestine in response to protein source has not been sufficiently tested in the early weaned pig. Cera et al. (1988) reported a slight, but consistently, larger villus height in pigs fed a basal diet without added dried whey although diet had little effect on the marked morphological response to weaning observed in the small intestine. Similarly, Hancock et al. (1988) found no relationship between intestinal form and function in pigs fed soybean flakes with different degrees of processing. Hoppe et al. (1989) tested the effect of postweaning diet on early weaned pig intestinal morphology and function. Treatments were a simple corn-soybean meal diet and a corn-complex protein and fat diet.

They concluded that intestinal morphology and function were not affected by type of diet, but morphology and feed consumption were affected by day postweaning. The change in villus shape corresponded to a trend of less xylose absorbed 5 to 7 d postweaning. Grant et al. (1987) reported that the peptidase activity of 7 and 14 day old piglets fed milk replacer in which 20% of the milk protein was replaced by soy protein concentrate was lower than that of piglets fed an all milk protein milk replacer. Moore et al. (1988) reported that jejunal villus morphology of pigs fed alfalfa meal diet were characterized by a loss of epithelial cells and microvilli at the villus apex, and ileum villi were blunted and frequently folded in pigs fed a 15% soybean hull diet. The mechanism by which high fiber intake may impare nutrient absorption are not understood completely, however, studies indicate that chronic intake of dietary fiber decreases intestinal nutrient transport in rats (Schwartz et al., 1982; Freemann, 1984).

Mucus secretions of the goblet cell form the primary barrier between the luminal contents and the intestinal epithelium. Disturbances in goblet cell populations at weaning may result in the ensuing poor performance. Dunsford et al. (1989) reported that weaning per se and not the form of dietary soybean protein influenced goblet cell concentrations in pigs weaned at 21 days of age.

Although previous studies have indicated that dietary protein may be affecting intestinal histomorphology and immune response of weaned pigs, none have evaluated the specific effects of different dietary protein sources on histomorphology. If different protein sources cause different histological changes post weaning, it may be possible to develop diets that will minimize or prevent adverse response. Such diets should result in better performance during the first 10 days after weaning and would be an economic benefit to the swine industry. Although soybean meal supplemented diets provide good performance, the antigenicity of soybean meal may be suppressing pig performance during the critical period just following weaning.

Antigenicity of Soybean Protein

As use of soybeans for food becomes more widespread and consumption of soybean proteins increases, problems relating to soybean sensitivity or allergy might be expected to arise. In contrast to antinutritional factors and toxins associated with feedstuffs, allergens display their effects only in those individuals possessing hypersensitivity to allergens.

It has been reported that diarrhea following weaning in the pig may result from a transient intestinal hypersensitivity to antigen components of the weaning diet (Miller et al., 1984a). It has been suggested that while consumption of small amount of creep feed primes hypersensitivity, consumption of large amounts before weaning causes the animal to become tolerant to the dietary antigens it meets later. Subsequently, Miller et al. (1984b) demonstrated that withholding creep feed before three week weaning had a protective effect against diarrhea after weaning. On the other hand, diarrhea is frequently associated with the isolation of a relatively limited number of enteropathogenic serotypes of Escherichia Coli form either the feces or the small intestinal contents (Smith and Jones, 1963; Svendsen et al., 1974) although their presence alone is not sufficient to cause diarrhea (Kenworthy and Crabb, 1963; Craven and Barnum. 1971). It has been suggested that the pH of the gastric contents increases after weaning to non-bacterial values and that this change allows the proliferation of enteropathogenic strains of E. Coli in the stomach and from here they gain access to the small intestine (Schulman, 1973).

Conventional milk replacers for young animals are based largely on milk products, which are not only costly but are likely to be used increasingly for direct human consumption. There is considerable incentive, therefore, to seek alternative materials for young animal diets and in recent years a variety of potential protein sources has been examined. Of these, soybeans have attracted most attention because they are readily available and have a reasonably well balanced amino acid composition and considerable progress has been made in rectifying their known anti-nutritional properties.

Despite treatment by a variety of industrial processes to inactivate these anti-nutritional substances (Hemagglutinins and trypsin inhibitors) reports on the replacement of milk protein in the feeding of young pigs (Pond et al., 1971a) and calves (Stobo and Roy, 1978) have indicated a relative deficiency in nutritional performance and there is evidence that digestive disturbances occur, which are probably more attributable to immune mechanisms that are currently understood as an anti-nutritional constituents of soybean (Smith and Sissons, 1975).

The allergenicity of soybean protein was first noted by Duke (1934), although subsequent tests in the guinia-pig suggested that soybean protein had, innately, only weakly sensitizing properties (Hill, 1942; Ratner and Crawford, 1955).

It has been suggested that feeding soybean protein rather than bovine milk from birth results in a lower incidence of allergic disease (Glaser and Johstone, 1953) but this has been disputed by a number of authors (Halpern et al., 1973; Kjellman and Johansson, 1979). There is some evidence that soybean protein may be less antigenic than bovine milk protein (Halpern et al., 1973; May et al., 1982). However, this situation is not clear and serum antibody response in infants given soybean protein or milk protein based formula (Eastham et al., 1978) indicated that soybean protein is at least as antigenic as milk protein. Of the many antigenic constituents present in soybean endosperm, most are denatured or removed during industrial processing.

Differing processing methods have been shown to affect the antigenicity of soybean protein based milk substitutes for preruminant calves (Sissons et al., 1979). Heppel et al. (1987) suggested that although the guinia pig is a convinient animal to use for in vivo studies of antigenicity, there is no evidence that sensitization to dietary protein results in any adverse physiological problems in the gastrointestinal tract. In contrast, the preruminant calf has been shown to develop severe gastrointestinal disorders following the introduction of non-bovine milk protein into its diet and these disorders possess many of the features of an allergic response (Kilshaw and Sissons, 1979; Kilshaw and Slade, 1982). The digestibility of soybeans in calf feeds can be improved by processing methods which reduce the levels of antigenic glycinin and beta-conglycinin (Stobo et al., 1983). Poor digestibility was thought to result from an allergic reaction to antigenic soybean. Kilshaw and Sissons (1979) also suggested that undenatured glycinin and beta-conglycinin fed to the young calf in milk replacer diets containing soybean products can cause gastrointestinal allergy, and that there is evidence for similar reactions occurring in man. However, the occurrence of an antigenic response to soybean protein in the young pig has not been adequately tested. Dunsford et al. (1989a) suggested that the greatest effects on intestinal microscopic anatomy occured from feeding the soybean meal diet. In addition to malformed villi and increases in lamina propria depth, there also were indications of increased immunological activity occuring in the intestinal wall. They also indicated a higher concentration of lymphocytes and plasma cells in the lamina propria of pigs fed soybean meal than in pigs fed milk diets.

Newby et al. (1984) have suggested that an immune response at the intestinal level from dietary antigens may be the cause of post-weaning diarrhea and changes in intestinal structures. They also reported that feeding weaned pigs properly heated full-fat soybean protein extract as the only protein source caused diarrhea, reduced xylose absorption and caused an immune response to soybean antigen, as measured by changes in ear thickness following injection of a saline-extracted soybean antigen. These effects were greatest 5 d postweaning but returned to preweaning levels by d 11 or 13. Giesting et al. (1987), however, did not find differences in post-weaning skin fold thickness(after injecting a soybean extract) in pigs receiving either soybean meal or fish meal as the sole source of dietary protein. Although the conflicting results of Newby et al. (1984) and Geisting et al. (1987) do not make it possible to conclude that feeding soybean meal post-weaning causes a systemic immune response, a local immune response at the intestinal level to antigens in soybean meal may have occured (Dunsford et al., 1989a).

Wu et al. (1988a) conducted xylose absorption test as an indicator of allergic reaction to feed to investigate the effects of five different protein sources on intestinal absorptive ability of pigs weaned at 28 days of age. Protein sources in this study included dried skim milk, isolated soy protein, soy protein concentrate, soybean meal, and fish meal. No significant differences of plasma xylose concentrations were observed among the five treatments; although plasma D-xylose concentrations in soybean meal and fish meal treatments had lower values than those of others. In another experiment, Wu et al. (1988b) observed that pigs weaned at 18 days of age and fed a soybean meal and full-fat soybean meal diet maintained lower concentrations of plasma xylose. The results showed that pigs fed soybean meal during post weaning not only had a lower intestinal absorptive capacity, but also had a tendency toward an allergic reaction to dietary antigen.

Lactose and Protein Utilization

The digestive enzymes of the young pig change dramatically the first few weeks of life. Lactase, the enzyme that cleaves beta 1,4 linkage in lactose, the predominant carbohydrate in milk, is high at birth and decreases with age. On the other hand, the enzymes amylase, sucrase and maltase, necessary to break down the carbohydrate in cereal grains, are low at birth and increase with age. Numerous studies have demonstrated that milk protein is more efficiently utilized by young pigs than protein from soybean meal until the pig is about five weeks of age.

A considerable quantity of lactose is necessarily indigenous in a baby pig diet in which dried skim milk is employed as the primary source of protein since dietary lactose has been shown to produce various physiological effects when fed to young animals (French and Cowgill, 1937; Bacigalupo et al., 1950; Lengeman, 1959).

Walker et al. (1986) demonstrated that the effect of protein source for early weaned pigs is more evident during the first 2 weeks postweaning. After weaning, carbohydrates usually comprise approximately 70% of the diet. The ability of young pigs to utilize carbohydrates depends on the form and source (Cunningham, 1959; Sewell and Maxwell, 1966). Sewell and West (1965) reported that pigs receiving diets containing additions of lactose gained weight at a significantly faster rate than pigs consuming diets containing isolated soy protein without lactose. Pigs fed diets containing isolated soy protein plus lactose required less feed per pound of gain than pigs receiving a diet containing soybean protein without lactose. Significant increases in apparent digestibility were obtained for diets containing lactose as compared with the basal diet containing soybean protein without lactose. Digestibility of the ether extract fraction of the diets was likewise improved by supplementation with lactose. Dietz et al. (1988) reported that pigs fed isolated soy protein plus lactose had a higher performance as compared to those fed dried skim milk.

The improvements in performance of early weaned pigs fed diets containing milk products are apparently due to the ability of the young pig to utilize the carbohydrate and protein fractions of milk more effectively than those components of plant feed ingredients.

In a study conducted to compare combinations of protein and carbohydrate sources from milk or plant origin and determine their effects on nutrient digestibilities of early weaned pigs, Turlington et al. (1989) demonstrated that energy and nutrient digestibilities for weaned pigs were greater when diets contained casein or lactose rather than soybean meal or dextrose, and milk protein causes a greater improvement in digestibility than milk carbohydrate.

Leibholz (1982) and Woodard and Carroll (1985) found that nutrient digestibilities were lower when diets contained soybean meal, which indicates that milk protein plays a major role in improving nutrient digestibility. Turlington et al. (1989) reported similar findings. Although the carbohydrate sources had little effect on digestibility, the carbohydrate fraction of the diet may account for some of effects observed among the digestibility coefficients. The soybean meal treatments had a greater portion of their carbohydrates coming from soybean meal, particularly structural carbohydrates (NDF). These nondigestible carbohydrates may play a role in limiting the protein availability from soybean meal (Jones et al., 1977; Walker et al., 1986).

It has been shown that lactose improved ileal digestibilities when combined with soybean meal, but little response was obtained when it was combined with casein. Sewell and West (1965) reported that the presense of lactose improved digestibility of diets containing soybean proteins as the primary source of dietary protein. However, Wilson and Leibholz (1979) found no differences in apparent nutrient digestibilities for young pigs fed diets containing lactose or wheat starch when casein was the primary protein source.

Different rates of passage may explain different nutrient digestibilities caused by feed ingredients. Maner et al. (1962) and Wilson and Leibholz (1981b) reported that soybean proteins cause faster digesta flow than milk proteins. Buraczewski et al. (1971) reported that lactose is more effective in delaying stomach emptying than corn dextrin. These observations are supported by the data from an experiment conducted by Turlington et al. (1989), which suggest that milk protein and milk carbohydrate reduce digesta flow rate. These data reported suggest a 5 to 10% improvement in digestibility for the early weaned pig when milk products are fed. Also, milk carbohydrate appears to have less effect on improving nutrient digestibility than milk protein, for young pigs weaned at an early age.

Differences between Ileal and Fecal Digestibility Values

Many studies have been carried out on the topic of amino acid digestibility in swine during the last two decades. Amino acid digestibility coefficients obtained by the fecal analysis method are, for most amino acids in most feedstuffs, higher than those obtained by the ileal analysis method. In some of the studies, net synthesis of methionine and lysine has been reported in the large intestine (Zebrowska, 1978b; Low, 1980; Sauer et al., 1982; Tanksley and Knabe, 1982). Therefore, depending on the amino acid and on the feedstuff, digestibilities obtained by the fecal analysis method overestimate or underestimate those obtained by the ileal analysis method.

Austic (1983) calculated the average differences in apparent digestibilities of amino acids as determined by sampling ileal contents and feces. The average difference was 6.5 percent. The difference was greater for feedstuffs of low protein digestibility than of high protein digestibility, with the exception of cottonseed meal. Tanksley et al. (1981) suggested that this exception was due to an inhibitory effect of gossypol on the microflora or to resistance to bacterial breakdown of the protein-gossypol complex formed during the processing of cottonseed meal.

Differences between the ileal and fecal digestibility coefficients may also be dependent on the amount of carbohydrate that reachs the large intestine, and that can be fermented. Replacement of corn starch by raw potato starch in diets for pigs increased the proportion of bacterial proteins and reduced the apparent protein digestibility (Mason et al., 1976). Infusion of corn starch via a cannula placed in the distal part of the ileum, in pigs fed semi-purified diets with meat and bone meal or soybean meal as protein sources, increased the excretion of nitrogen in feces and decreased the excretion of nitrogen in urine, without affecting the amount of nitrogen retained (Misir and Sauer, 1982a). Upon starch infusion, the protein digestibility decreased from 73.9 to 69.1% in meat and bone meal, and from 84.7 to 82.5% in soybean meal. The decreases in the fecal digestibilities of the indispensible amino acids ranged from 1.4 (arginine) to 7.8 (valine) percent in meat and bone meal and from 2.1 (argine) to 10.2 (threonine) in soybean meal.

In studies by Zebrowska et al. (1981) infusion of wheat starch into the cecum of pigs decreased the apparent fecal digestibility of protein by 3-4%. The fecal digestibility of some of the indispensible amino acids decreased by 4-7%. Zebrowska et al. (1978b) showed no effect on protein digestibility when cellulose was infused into the cecum, indicating that only a small fraction of cellulose was fermented by the microbial population in the large intestine.

The ileal analysis method should be considered a further improvement, as compared to the fecal analysis method, for determining amino acid digestibilities. When casein was given the level of free amino acids in portal blood was high and that of urea low. Other reports also clearly show that protein or amino acids infused into the large intestine make little or no contribution to the protein status of the pig (Hodgdon et al., 1977; Gargallo and Zimmerman, 1981; Just et al., 1981).

Amino acid may be synthesized by the microflora of the large intestine and there is evidence from experiments with ^{15}N that some of the synthesized amino acids can be transported into the blood (Niiyama et al., 1979).

A common argument in favor of ileal cannulation is that the hindgut microflora degrade amino acids and this has the effect of inflating digestibility coefficients. However, microbial synthesis of amino acid has the reverse effect. Low (1979) found net accumulation of some amino acids in the large intestine. The amount of synthesis is affected by the nature of the digesta reaching the hindgut. Infusion of carbohydrate into the cecum increased amino acids synthesis and reduced urinary nitrogen output (Misir and Sauer, 1982).

Fermentation in the hindgut is affected by the time required for passage of feed residues and by the supply of nitrogen and energy. Using wheat based diets, Ivan and

Farrell (1976) found almost complete digestion of starch in the small intestine of the pig which may explain why the differences between ileal and whole tract digestibilities were relatively small for most amino acids. Bayley et al. (1974) indicated that the hindgut effect was greatest for poor quality proteins which explains why maltreatment (overheating) of soybean meal was detected by ileal, but not fecal, digestibility measurements.

Although the weight of evidence favors ileal rather than fecal digestion as an estimate of availability, it is not conclusive. For example, cecal infusion of starch may result in a amino acid synthesis but in practice the amount of starch entering the cecum may be small. (Misir and Sauer, 1982). Similarity, claims that large proportions of the amino acids entering the cecum are deaminated may have little significance if more than 90% of dietary and endogenous amino acids are absorbed before reaching the cecum.

In addition, processing conditions may also influence the differences between the ileal and fecal digestibility coefficients. Excessive heat treatment may denature protein to the extent that it becomes resistant to bacterial fermentation.

Before application of only ileal amino acid data in formulating diets, more experiments are needed where performance and carcass data are related directly to ileal availabilities.

Antinutritional Factors in Soybeans

Soybean meal is one of the most important plant proteins in livestock feeding in the United States as well as in many countries all over the world such as Korea, Brazil and Columbia.

A number of soybean components have been isolated and suggested as antinutritional factors. Trypsin inhibitor was one of the first soybean components proposed as an antinutritional factors. Following its discovery (Bowman, 1944; Ham and Sandstedt, 1944), trpsin inhibitor was crystallized by Kunitz (1945). Other factors include hemagglutinins, saponins, isoflavons, goitrogens, phytates and lectins.

Although the protease inhibitors are found in most legumes, those that are present in soybeans have received the most study (Liener and Kakade, 1980). Based largely on experiments involving the use of small animals, the growth-depressing effect of these inhibitors has been attributed to its effect on what is generally referred to as the negative feedback mechanism. Briefly, the inactivation of trypsin in the gut by trypsin inhibitors induces the intestinal mucosa to release cholecystokinin(CCK), a hormone which stimulates the acinar cells of the pancreas to produce more trypsin as well as other digestive enzymes such as chymotrypsin, elastase and amylase.

Leterme et al. (1989) suggested that as the pancreatic enzymes content in the sulfur containing amino acids is high, the enhanced excretion would reduce dramatically the intestinal availability of these amino acids which are already deficient in peas. In their trial, the apparent digestibility of the 2 pea varieties by growing pigs did not differ significantly($p>.05$) for the organic matter and the crude energy, but the apparent digestibility of crude protein was significantly lower ($P<.05$) for the variety Progreta than for Finale. This difference may be attributed to the trypsin inhibiting activity of Progreta which is three times as high as Finale.

Most investigators have generally used trypsin of bovine origin to measure the trypsin inhibitor content of various legumes despite the fact that the nutritive value of the protein may have been evaluated in an entirely unrelated animal species. Yet in vitro studies on the inhibition of the proteases in the pancreatic juice of different animals have revealed marked differences in the degree to which these enzymes are inhibited by the protease inhibitors of various legumes (Krogdahl and Holm, 1983; Rascon et al., 1985; Hanlon and Liener, 1986).

The presence or absence of the negative feedback mechanism also appears to be species dependent. Negative feedback control has been demonstrated to be operative in the rat, mouse, chicken and hamster and is accompanied by an enlargement of the pancreas when these animals are fed a soy flour. Other animals, however, such as the dog, calf, pig, guinia pig and monkey do not develop pancreatic hypertrophy despite the existence of the negative feedback mechanism, at least in case of the pig and calf (Schneeman and Gallahen, 1986). Yen et al. (1977) also reported that the physiological response of the growing pig to raw soybean differs from that of the rat and chick in that the pancreas does not enlarge and pancreatic enzyme synthesis is not stimulated in the pig. The growth failure observed in pigs fed raw soybeans apparently results from reduced feed intake and inhibition of protein digestibility. It is evident that more research is needed in order to clarify the role of CCK in negative feedback mechanism as it relates to the effect of various trypsin inhibitors on the pancreas of different species of animals.

Aside from the rat (Rackis et al., 1975), information is lacking concerning the practical question of what constitutes a safe level of trypsin inhibitor in the diet for other animal species including man. To provide such information will require studies with diets containing various levels of trypsin inhibitor activity using selected animal species.

Most dietary lectins are resistant to gut proteolysis to an appreciable but variable extent. By binding to membrane receptors of epithelial cells of the small intestine and subsequent endocytosis, lectins may interfere with the digestion and absorption of nutrients, increase wasteful protein and glycoprotein synthesis and secretion, speed up cellular turnover, cause hyperplasia and modify gut immune function. A combination of some or all of these effects reduces the efficiency of nutrient utilization. As a proportion of all dietary lectins, even those which are relatively non-toxic, is systemically absorbed, lectins may affect immunity, the endocrine system and general metabolism. Thus both soya and kidney bean lectins reduce blood insulin concentration for the entire period of feeding, while glucagon levels are increased by kidney bean. The net result of all the changes in hormone levels shifts the balance of general metabolism towards increased catabolism, i.e, increased lipolysis, muscle breakdown and mobilization of liver glycogen. Accordingly, through the direct effects of systemically absorbed lectins or, indirectly, through the modulation of the endocrine system by gut hormones, all lectins introduced into the alimentary tract may interfere with metabolic processes of the body. With most lectins studied to date the changes induced lead to increased catabolic breakdown of all body components, proteins, lipids and carbohydrates, retard growth and affect health (Pusztai, 1989).

Phytate, the salt of phytic acid, is a cyclic compound (inositol) containing six phosphate radicals. It is present to the extent of 1 to 5% of the dry weight of legume seeds. Its physiological significance lies in the fact that it readily chelates with di- and tri-valent metal ions such as calcium, magnesium, zinc and iron to form poorly soluble compounds that are not readily absorbed from the intestines. Thus phytate has generally been regarded as an antinutritional factor which interferes with the bioavailability of minerals from plant sources (Reddy et al., 1982; Forbes and Erdman, 1983). It has been shown that high dietary calcium accentuates the effect of phytate on zinc bioavailability. The formation of Zn-Ca-Phytate complexes in the upper intestinal tract of monogastric animals is believed to be a major mechanism by which phytate reduces zinc bioavailability. Although the ability of phytate to interfere with the availability of minerals accounts for its major antinutritional effect, phytate has also been shown to interact with the basic residues of proteins. It is not surprising, therefore, that phytate inhibits a number of digestive enzymes such as pepsin, pancreatin and alpha-amylase. Inhibition may also result from the chelation of calcium ions which are essential for the activity of trypsin and alpha-amylase, or possibly to an interaction with the substrates for these enzymes.

Saponins are steroid or triterpenoid glycosides which are characterized by their bitter taste, foaming properties and their hemolytic effect on red blood cells. They are widely distributed among plants and are present in significant levels in such legumes as alfalfa, soybeans and chick peas. Soybean saponins apparently have little effect on the growth of experimental animals; neither saponin or sapogenin could be detected in the blood of chicks, rats and mice following the oral administration of soybean saponin (Gestetner et al., 1968). Some saponins from non-edible plants readily increase the permeability of the small intestinal mucosal cells thereby inhibiting the active transport of nutrients, but, at the same time, facilitating the uptake of materials to which the gut would normally be impermeable (Johnson et al., 1986). It is significant to note, however, that soybean saponins were much less effective in this respect.

CHAPTER III

EFFECT OF SOURCE OF DIETARY PROTEIN ON PERFORMANCE OF EARLY WEANED PIGS

Summary

The effect of dietary protein source on growth rate, feed efficiency and apparent fecal dry matter, nitrogen, ash and amino acid availability was studied in two trials utilizing 72 yorkshire pigs weaned at 21 days of age. Protein sources used as the primary lysine source were dried skim milk protein (DSM), two isolated soy proteins (ISP I;soluble, ISP II;insoluble), three soy protein concentrates (SPC I, SPC II and SPC III) and 50% soybean meal (SBM). Seven experimental diets were formulated to contain 1.5 percent lysine and 40 percent dried whey on an as fed basis. Lactose was added to the soybean protein diet at a level equal to that provided by the dried skim milk diet. Estimates of feed intake, body weight gain and efficiency of feed utilization were obtained weekly while the apparent availability of dry matter (DM), ash, nitrogen (N) and amino acids (AA) was estimated from fresh fecal samples collected at the end of the first and second week on trial. Pigs were housed in an environmentally controlled room in individually elevated pens with

temperature maintained at 86^{0}F and 84^{0}F for weeks 1 and 2 respectively. Trial length was fourteen days. All the pigs were fed a common 18% crude protein starter diet for an additional three week period to evaluate carry-over effects on gain and feed efficiency. Average daily gain and efficiency of gain was higher in pigs fed the dried skim milk diet, the two isolated soy protein diets and the three soy protein concentrate diets when compared to pigs fed the soybean meal diet during week 1, week 2 or for the two week period (period 1). Average daily feed intake during the first week was lowest (P<.05) in pigs fed the soybean meal diet. During the second week on trial and for the two week period, average daily feed intake among the dietary treatments was similar. Averaged over the 2 week trial, the average daily feed intake was 351, 345, 360, 350, 345, 340 and 290 g and the average daily gain was 273, 281, 298, 283, 271, 267 and 194 g for the pigs fed the DSM, ISP I, ISP II, SPC I, SPC II, SPC III and SBM diet, respectively. Average daily gain and average daily feed intake were similar among the seven dietary treatments during the subsequent 3 week period (period 2). During the first week and for the entire 14 day experimental period, lower G:F (P<.05) was observed for pigs fed the soybean meal diet diet than for pigs fed any of the soybean protein diets or the dried skim milk diet. Feed efficiency during the second period was not affected by treatments. Higher apparent fecal availability of lysine (P<.05) and valine

(P<.05) was observed in pigs fed the dried skim milk diet than for pigs fed any of the soybean protein diets, however, the availability for the remaining essential amino acids was similar among the dried skim milk diet, the two isolated soy protein diets and the three soy protein concentrate diets. The average apparent fecal availability for the essential amino acids was 87.5, 86.0, 86.2, 85.9, 85.8, 85.6 and 80.3% for the DSM, ISP I, ISP II, SPC I, SPC II, SPC III and SBM diets, respectively during the overall 14 day experimental period. The apparent fecal availability of dry matter and nitrogen was lower (P<.01) in pigs fed the soybean meal diet compared to those fed the other protein sources. However, there were no significant differences among the dried skim milk, the two isolated soy protein and the three soy protein concentrate diets for apparent availability of dry matter, nitrogen and amino acids.

Introduction

Subjecting a three week old pig to the distresses associated with weaning commonly results in a reduction of feed intake, little or no weight gain and diarrhea.

Due to the high cost of milk proteins, soybean flakes have been supplemented with essential amino acids and /or digestive enzymes as well as treated with alkali or acid to improve performance and efficiency of utilization.

It has been established that pigs can be reared from 2 or 3 days of age using diets containing an isolated soy protein supplemented with methionine (Sewell et al., 1953; Cunningham and Brisson, 1957), but milk protein supports better growth (Maner et al., 1961; Schneider and Sarett, 1966). Dried skim milk was also superior to soybean meal for pigs weaned either at 10 (Hays et al., 1959) or 21 days of age (Kellogg et al., 1964). The etiology of lower performance of young pigs fed soybean proteins has not been determined clearly but possible explanations include : 1) lower amino acid availability in soybean proteins than in milk proteins; 2) substance(s) present in soybean proteins may be detrimental to the health of the intestinal villi; 3) protease or disaccharidase levels may be insufficient for optimal utilization of non-milk protein or energy. Many attempts have been made to identify the factors responsible for the inferior performance of young pigs fed soybean protein diets in an effort to improve soybean protein utilization by the early weaned pigs. Alkali treatment of soybean proteins has been shown to result in an improvement of pig performance (Lennon et al., 1971), while Coalson et al. (1972), Jones et al. (1977) and Wilson and Leibholz (1981a) reported no improvement in gain and efficiency of pigs fed diets containing soybean protein treated with either acid or alkali. Recently, isolated soy proteins, which are treated by alkali and soy protein concentrates, which are treated by acid have been manufactured and may offer an alternative protein source for the early weaned pig. Recently, two studies (Dietz et al., 1988; Geurin et al., 1988) indicate that some sources of refined soybean protein could serve as a suitable replacement for milk protein. Development of specialized soybean proteins which can be utilized in the diet of early weaned pigs could be a means of reducing the inclusion rate of more expensive milk proteins in the diet of early weaned pigs. This study was conducted to determine the effect of source of protein and method of processing of soybean protein upon performance and dry matter, ash, nitrogen and amino acid availability in pigs weaned at 21 days of age. All pigs were fed a common starter diet after the trial for a 3 week period to determine the effect of the 2 week trial period diet on subsequent performance.

Materials and Methods

Seventy-two Yorkshire pigs were used to study the effect of dietary protein source on the performance of early weaned pigs. Thirty-six pigs in each of two replication were alloted by sex, litter and weight to one of the seven dietary treatments after being weaned at 21 days of age, providing a total of 10 pigs per treatment. The average initial weight for all pigs on trial was 5.0 kg. One milk and six soybean protein sources were used in diets (Table 1.1) formulated to meet NRC (1988) requirements for the 5-10 kg pig. Protein sources were dried skim milk (DSM), two isolated soybean proteins (ISP), three soybean protein concentrates (SPC) and 50% crude protein solvent extracted soybean meal (SBM). All diets were formulated to contain 1.5% lysine from both milk and soybean protein sources as follows:

1. Dried skim milk-whey diet with 36% crude protein dried skim milk as the primary source of lysine.

2,3. Isolated soy protein-whey diet with 2 sources of isolated soy protein (one soluble and one insoluble) as the primary source of lysine. Lactose was added to this diet at a level equal to that provided by dried skim milk in treatment 1.

4,5,6. Soy protein concentrate-whey diet with three sources of soy protein concentrate as the primary source of lysine. Lactose was added to this diet at a level equal to that provided by the dried skim milk in treatment 1.

7. Soybean meal protein-whey diet with 50% crude protein soybean meal as the primary source of lysine. Lactose was added to this diet at a level equal to that provided by the dried skim milk in treatment 1.

Two isolated soy protein products (one soluble;PP-620; one insoluble;PP-HD-90) were provided by Protein Technologies International. The composition of the two isolated soy proteins are shown in table 3.3 and a schematic (Figure 3.1) illustrates how the product is produced.

Isolated soy protein is defined as the major proteinaceous fraction of soybean prepared from high quality, sound, cleaned and dehulled soybeans by removing a preponderance of the nonprotein components that shall contain not less than 90% protein (N*6.25) on a dry matter basis (Snyder and Kwon, 1988).

Three soy protein concentrates (Procon-plus, Promine and Promocalf) were provided by Central Soya. The composition of three soy protein concentrates is shown in table 3.3 and a diagram (Figure 3.2) illustrates the process of producing this product.

Soy protein concentrates are defined as the major proteinaceous fraction of soybeans prepared from high quality, sound, cleaned and dehulled soybeans by removing most of the oil and water soluble nonprotein constituents. Soy protein concentrate shall contain not less than 70% Protein (N*6.25) on a moisture free basis (Snyder and Kwon, 1988). Three processes are generally used to commercially produce soy protein concentrates: the aqueous alcohol leach, dilute acid leach and the moist heat and water leach. The processes are outlined in figure 3.2. The processes mainly differ in the methods used to insolublize the major proteins while the low molecular weight components are removed.

An edible grade of dried skim milk and whey were used in this experiment. Pigs were individually housed in metabolism crates measuring .47 by .76 m in an environmentally controlled feeding room maintained at 86^{0}F during the first week and was decreased 2^0F per week for the remainder of the experiment. Pigs had access to feed and water ad libitum throughout the trial. Pigs remained on trial for a 35 day period with pig weight and feed intake recorded weekly. Feed waste was collected in pans placed under individual feeders and then dried in order to more accurately estimate feed intake. During the first and second week of each replicate, chromic oxide was added to each diet at the rate of .25% to provide an indigestible marker for determining nutrient availability. A fresh fecal sample was collected from each pig on the last three days of the first and second week of each replicate and was immediately frozen and stored at -20^0C. Fecal samples collected over the two collection periods of each replicate were composited by treatment prior to lyophilyzation and grinding for laboratory analysis.

In replication 1, one pig was removed from experiment because of feed refusal due to unknown reason during the first week of the experiment.

Dry matter, ash and nitrogen content of both feed and feces were determined according to the AOAC (1980) methods. Chromic oxide was determined by an atomic absorption spectrophotometer method (Williams et al., 1962). Amino acid analyses were determined by ion-exchange chromatography using a modified Beckman model 6300 amino acid analyzer. Acid hydrolysis was conducted under nitrogen reflux in 6 N HCL for 22 h. The apparent fecal availability of DM, ash, N and AA were calculated using chromic oxide as the indigestible marker. Data for each response criteria were analyzed by least squares analysis of variance using the General Linear Models procedure of the Statistical Analysis System (SAS, 1984). The standard error reported for each period is the mean of the standard errors of all treatments. The model for average daily feed intake (ADFI), average daily gain (ADG), feed efficiency (FE) and weight gain included the main effects of replication, treatment, sex, litter within replication and the appropriate interactions.

Results and Discussion

The protein and amino acid composition of dietary protein sources and all the diets are shown in table 3.3 and 3.4. Crude protein as well as the essential amino acid such as arginine, phenylalanine and lysine were highest in the soybean protein sources while methionine and valine were highest in the dried skim milk protein. The remainder of the essential amino acids were similar among all the protein sources. All of the experimental diets have a similar content of lysine and methionine and histidine while the crude protein content of the two isolated soy protein and the three soy protein concentrate diets was higher than that of soybean meal diet with crude protein content of dried skim milk diet being intermediate.

The effect of dietary protein source on average daily gain during the 14 day experimental period (period 1) is shown in table 3.9. During the first week postweaning, pigs fed the dried skim milk, isolated soy protein and soy protein concentrate diets grew faster (P<.01) than those fed the soybean meal diet. The magnitude of response ranged from an 110% increase in average daily gain in pigs fed the ISP I to a 70% increase in average daily gain in pigs fed the SPC III diet when compared to gain of pigs fed the soybean meal diet. This result is not consistent with those reported by Walker et al. (1986a) who found that pigs fed the SPC diet during the first two week grew more slowly than those fed the SBM diet. This difference between the two reports may be due to the different processing methods or a more advanced processing method for the soy protein concentrates now available. Average daily gain was similar between pigs fed the two isolated soy protein diets or among pigs fed the three soy protein concentrate diets. Average daily gain of pigs fed the dried skim milk diet was similar to that of pigs fed the two isolated soy protein diets or the three soy protein concentrate diets. During the second week, pigs fed the soybean meal diet continued to grow more slowly (P<.01) than those fed either of the two isolated soy protein diets or the three soy protein concentrate diets, however, average daily gain in pigs fed the dried skim milk or the soybean meal diet was similar. Average daily gain over the entire 14 day experimental period was lower (P<.05) for pigs fed the soybean meal diet than for those fed the dried skim milk or any other soybean protein source diets, however this percentage difference was lower than that observed during the first week. Least square means for average daily gain during the entire 14 day experimental period for the DSM, ISP I, ISP II, SPC I, SPC II, SPC III and SBM treatments were .27, .28, .29, .28, .27, .26 and .19 kg/day, respectively. Average daily gain was similar among pigs fed the seven dietary treatments during the subsequent 3 weeks (Table 3.10) although pigs fed the soybean meal diet during period 1 continued to show reduced gains when compared to pigs fed any other diets.

Wu et al (1988a,b), using a xylose absorption test as an indicator of the allergic reaction to soybean antigens, found that pigs fed soybean meal post-weaning not only had a lower intestinal absorption, but also had a tendency toward an allergic reaction to dietary antigen. The absorption curves of plasma xylose concentrations showed that severe malabsorption apparently occurred by six days postweaning in pigs fed diets containing the dried skim milk or soybean meal, while no significant low peak in plasma xylose concentrations was observed in pigs fed the isolated soy protein or soy protein concentrate diets. They also suggested that adaptation time of feed was about 9 days postweaning for pigs fed dried skim milk and about 12 days for pigs fed full-fat soybean meal and soybean meal.

The effect of dietary protein source on efficiency of feed utilization was similar to that observed for average daily gain (Table 3.11). Pigs fed the dried skim milk, the two isolated soy protein diets and the three soy protein concentrate diets had a higher (P<.01) gain to feed ratio during the first and second week and for the entire 14 day experimental period than those fed the soybean meal diet, however, no significant differences were observed among the dried skim milk, the two isolated soy protein diets and the three soy protein concentrate diets. Least square means for G:F ratio during the first week were .85, .86, .86, .83, .79, .79 and .66 g gain/g feed for DSM, ISP I, ISP II, SPC I, SPC II, SPC III and SBM diets, respectively. Gain to feed ratio was similar among all treatments during the subsequent 3-week period (period 2).

Several studies have been conducted to compare performance and efficiency of feed utilization of pigs fed diets containing either milk or soybean protein sources (Kellogg et al., 1964; Leibholz, 1982; Mateo and Veum, 1980; Sherry et al., 1978; Veum et al., 1986; Walker et al., 1986a; Wilson and Leibholz, 1981a). They have reported higher average daily gain and improved efficiency of feed utilization for pigs fed milk protein diets compared to those fed isolated soy protein diets (Mateo and Veum, 1980; Wilson and Leibholz, 1981a: Walker et al., 1986a), soy protein concentrate diets (Giesting et al, 1985) or soybean meal diets (Combs et al., 1963; Dietz et al., 1988). On the other hand, Geurin et al. (1988) reported that when 21 day old pigs were fed an isolated soy protein-whey diet, average daily gains were not significantly different from those fed a dried skim milk diet and thus concluded that isolated soy protein can be used with whey to replace dried skim milk in pigs from 3 to 6 weeks of age. Giesting et al. (1985) also indicated that average daily gain of pigs fed a soy protein concentrate diet was similar to that of pigs fed a dried skim milk diet. Dietz et al. (1988) also suggested that pigs fed an isolated soy protein diet as a protein source showed higher performance when compared to those fed a dried skim milk diet. The 273 g/ day gain reported for pigs fed the dried skim milk diet as well as the 285 g/ day gain for the average of those fed the two isolated soy protein diets during the first two weeks of this study are fairly similar to values reported by Decuypere et al. (1981) of 275 and 279 g/ day for pigs fed milk and soybean protein diets, respectively.

The G:F ratios of .80 and .84 for dried skim milk and isolated soy protein diets during the first period of this study were higher than those reported by other workers for this age pig (Combs et al., 1963; Lecce et al., 1979; Walker et al., 1986a) which range from .54 to .67. Pigs fed the dried skim milk diet diet, the two isolated soy protein diets and the three soy protein concentrate diets had higher feed efficiency than those fed the soybean meal diet, however no significant differences were observed among the three dietary protein sources.

The effect of dietary protein source on average daily feed intake is present in table 3.12. Average daily feed intake during the first week was lowest (P<.01) in pigs fed the soybean meal diet when compared to pigs fed the dried skim milk, the two isolated soy protein and the three soy protein concentrate diets. Average daily feed intake was similar among pigs fed the dried skim milk, the two isolated soy protein and the three soy protein concentrate diets. The largest difference in feed intake was observed during week 1 where pigs fed the dried skim milk diet, the two isolated soy protein diets and the three soy protein concentrate diets during the first week consumed 40, 38 and 32% more feed per day than those fed the soybean meal diet, respectively. During the 2nd week on trial and for the two week period, average daily feed intake among the dietary treatments was similar.

Feed intake values reported here for the milk protein based diet are similar to those reported by other workers which range from .34 to .71 kg/ day (Combs et al., 1963; Lecce et al.,1979; Decuypere et al., 1981; Partridge, 1981; Walker et al., 1986a) but are higher than those reported by Geurin et al. (1988) of .24 kg/ day and by Dietz et al. (1988) of .26 kg/ day for this age pig. Average daily feed intake for pigs of a similar age fed isolated soy protein and soy protein concentrate based diets have ranged from .34 to .36 kg/ day with an average daily feed intake of .35 kg/ day reported here. Reported average feed intake levels of .58 and .54 kg/ day (Lecce et al., 1979; Partridge, 1981) for pigs fed the soybean meal protein based diets well exceed the .29 kg/ day reported in this study.

Initial pig weights (Table 3.14) averaged 5.00, 5.00, 4.97, 5.00, 4.97, 4.97 and 4.96 kg for DSM, ISP I, ISP II, SPC I, SPC II, SPC III and SBM treatments, respectively when placed on trial. After week 1, due to inferior gains by pigs fed the soybean meal diet, dietary protein source affected pig weights ($P<.05$) and by the end of week 2, pigs fed the soybean meal diet weighed 13, 15 and 12% less than pigs fed the dried skim milk, isolated soy protein and soy protein concentrate diets, respectively (Table 3.14). Differences in pig weight continued throughout the three week carryover period when pigs were fed a common diet. Pigs fed the soybean meal diet weighed 4 to 7% less at the completion of the trial when compared to the other dietary treatments, although these differences among treatments were not significant. No significant treatment by week interaction ($P>.92$) was observed and differences in weight during the final three weeks were primarily the results of differences observed in weight gain during the initial 2 week experimental period.

Soybean protein solubility may be a problem for the young pig. The majority of soybean proteins are classified as globulins, which are insoluble at their isoelectric points (pH 4-5) but dissolve at pH values above or below the isoelectric point. The pH of a pig's stomach contents at birth is 3.8 to 4.2 (Cranwell and Titchen, 1976). Thus, the insoluble soybean proteins may undergo little proteolysis before entering the small intestine. In our experiment, however, the solubility of the soybean proteins did not affect performance and nutrient availability of young pigs.

The apparent fecal availability of dry matter in pigs fed various protein sources is shown in tables 3.16 and 3.17. The apparent fecal availability of dry matter in pigs fed the soybean meal diet was lower (P<.05) than in pigs fed the DSM, the two ISP and the three SPC diets, however, no significant differences were observed among the DSM, the two ISP and the three SPC diets. The apparent availability of DM in pigs fed the two ISP diets was similar to that observed for pigs fed the the three SPC diets but higher (P<.01) than that observed in pigs fed the SBM diet. DM availability of pigs fed the DSM diet was similar to that of pigs fed the two isolated soy protein and the three soy protein concentrate diets.

Pigs fed the SBM diet during the second week postweaning had higher (P<.05) DM availability than those during the first week postweaning (Table 3.18). Comparision between the 2 periods for DM availability could not made because of lack of data.

The apparent fecal availability of DM (92.64%) reported by this study for pigs fed the DSM diet was higher than those (85 to 87%) reported by Owsley et al. (1986) and Walker et al. (1986a) in pigs weaned at 28 days of age. Availability of DM, however, was lower than the 95 to 98%

range reported by other workers (Mateo and Veum, 1980; Wilson and Leibholz, 1981a and 1981b). The apparent fecal availability of DM (92.3%) reported for pigs fed the ISP diet was similar to those reported by several previous researchers (Mateo and Veum, 1980; Owsley et al., 1986; Wilson and Leibholz, 1981a and 1981b) which range from 86.9 to 94.5%. Similarly, differences in the apparent fecal availability of DM between the DSM and the SBM diets or the ISP and the SBM diets reported in this study are consistent with differences reported by several workers (Hays et al., 1959; Walker et al., 1986a; Wilson and Leibholz, 1981a,b) for pigs fed diets with similar sources of dietary protein. Wilson and Leibholz (1981b) also reported the digestion of DM over the total digestive tract of pigs fed milk, isolated soy protein or soybean meal diets at 28 days of age was 97.7, 92.5 and 87.4%, respectively. No significant differences were observed in the apparent availability of ash among the dietary treatments and availability was similar at both sampling periods. Differences in dry matter availability among the soybean protein sources may be due to the removal of complex indigestible carbohydrates during the isolation and extraction procedure in ISP and SPC as illustrated in figures 3.1 and 3.2.

The apparent fecal availability of nitrogen differed among dietary treatments(P<.05) and was lowest in pigs fed the SBM diet (Tables 3.19 and 3.20). No significant differences among the DSM, the two ISP and the three SPC diets were observed. Pigs fed the DSM diet during the 1st week after weaning had 1.79, 2.07 and 13.6% higher N availability than those fed the two ISP, the three SPC and the SBM diets, respectively, although no significant differences were observed among DSM, two ISP and three SPC diets. There were no significant differences either between the two isolated soy proteins or among the three soy protein concentrates. Nitrogen availability (92.13%) reported for pigs fed the ISP diets in this study is consistent with values reported by other workers for this age of pig (Ducuypere et al., 1981; Owsley et al., 1986; Wilson and Leibholz, 1981a and 1981b) who reported values ranging from 88.4 to 95.7% in pigs fed isolated soy protein diets. However, N availability reported for the average of pigs fed the DSM diet is lower (92.60%) than values (95.8 to 98.6 %)reported in the literature for this age of pig (Wilson and leibholz, 1981c; Veum et al., 1986). The small increase (1 to 2%) in the apparent availability of nitrogen with increasing age of the pigs from 28 d to 35 d was observed when diets containing soybean proteins were fed, but the apparent availability of nitrogen did not improve with increasing age of pigs fed the milk diet. The availabilities of lysine and threonine are of particularly interest because these are often present in limiting amounts in diets for pigs. The apparent fecal availability during the first week after weaning was higher for lysine ($P<.05$) and phenylalanine($P<.05$) in pigs fed the DSM diet than for pigs fed any of the soybean protein diets (Tables 3.19 and 3.20). The apparent availability of these two essential amino acids in pigs fed the DSM diet was higher (P<.05) than for pigs fed the SBM diet with pigs fed the two ISP and the three SPC diets being intermediate. Phenylalanine availability in pigs fed the DSM diet during the first week after weaning was higher (P<.01) than that of pigs fed any other protein source, however, during the second week there were no significant differences among the DSM, the two ISP and the three SPC diets. On the other hand, valine availability in pigs fed the DSM diet during the first week after weaning was similar among dietary treatments except the SBM diet but during the second week after weaning availability of the same amino acid in pigs fed the DSM diet was higher (P<.05) than that of pigs fed the two ISP or the three SPC diets. Differences in apparent fecal availability were not observed (P>.1) for the other essential amino acids, however, the actual availability of arginine and histidine was higher in pigs fed the two ISP and/or the three SPC diets than in those fed the DSM diet. For pigs at 28 days of age, threonine and phenylalanine showed the lowest apparent digestibility of the essential amino acids while lysine, arginine and tyrosine had the highest apparent digestibility. Of the non-essential amino acids, serine, glycine and alanine were poorly digested. For 35-d-old pigs, threonine, valine, glycine and alanine had the lowest digestibility of all dietary treatments. Arginine, lysine and tyrosine had the highest apparent digestibility. Of the non-essential amino acids, alanine and glycine had the lowest apparent digestibility. Pigs fed the soybean meal diet had a significantly (P<.05) improved essential amino acid availability (2.1%) with increasing age from 28 to 35 d. These results are consistent with results of Hays et al. (1959). Availability did not improve with increasing age in pigs fed the DSM diet, the two ISP diets and the three SPC diets. Differences in the fecal availability among dietary treatments for the nonessential amino acids were observed (Tables 3.19 and 3.20). Availability of proline and glutamic acid was highest in pigs fed the DSM diet and the lowest in pigs fed the SBM diet with the availability of these two nonessential amino acids in pigs fed the two ISP and the three SPC diets being intermediate. The apparent fecal availability of the remaining nonessential amino acids was similar among pigs fed the DSM diet, the two ISP diets and the three SPC diets, however pigs fed the SBM diet had the lowest (P<.01) nonessential amino acid availability. Availability values of amino acids in pigs fed the DSM diet and ISP diets reported in this study were fairly similar to the values of 86.8 and 84.0% for pigs fed the milk diet and isolated soy protein diets, respectively reported by Wilson and Leibholz (1981d). Both the ISP and SPC diets appeared to improve AA availability when compared to the SBM diet, while no significant difference was observed between the two ISP and the three SPC diets. Similarly, no differences were observed either between the two ISP diets or among the three SPC diets. The differences observed in fecal AA availability between dietary protein sources during the 2nd week after weaning, especially between the DSM and SBM diets, were not as large as differences observed among these same sources at the end of week 1 after weaning. The apparent fecal availability of AA in pigs fed the SBM diet increased with increasing age of pigs from 78.2% at 28 d of age to 80.3% at 35 days of age. However, the availability of amino acids in the milk protein diet did not change with increasing age of pigs. These nutrient availability data are consistent with performance data (Sohn and Maxwell, 1990). It is thought that the reduced performance of young pigs fed the SBM diet is the result of the lower availability of amino acids as compared with pigs fed the dried skim milk, the two isolated soy protein and the three soy protein concentrate diets. The lower digestibility in pigs fed the SBM diet may be attributed to the lower hydrolysis of soybean proteins in the small intestine as reported by Wilson and Leibholz (1981c). Dunsford et al. (1989a) suggested that feeding a high concentration of soybean meal to the pig post-weaning had a detrimental effect on the small intestine. Villus height decreased dramatically the first 3 d postweaning, with a continuing decline until 12 d post weaning. Hampson and Kidder (1986) also reported that jejunal villus height declined dramatically by 5 d after weaning, with a recovery of villus height by day 11 postweaning.

Colvin and Ramsey (1968) reported that treatment of soybean flour with acid or alkali may improve its nutritive value for calves. Treatments such as these may act by destroying the allergic factors. Poor digestibility of pigs fed the SBM diet is thought to result from an allergic reaction to antigenic constituents such as glycinin or beta-conglycinin which may affect the function of the small intestine. No significant differences in nutrient availability of pigs fed the DSM, the two ISP and the three SPC diets were observed. This phenomenon may result from the removal of antigenic materials present in soybean endosperm during industrial processing for production of isolated soy proteins or soy protein concentrates.

From these results it can be concluded that in the 28 to 35 d old pigs, soybean protein isolates or concentrates but not soybean meal are digested as well as milk protein as shown by the measurements of apparent digestibility and performance.

An increasing demand of milk for human consumption has caused higher prices and resulted in a search for sources of protein that can nutritionally replace milk proteins. The present results suggest that selected sources of both isolated soy proteins and soy protein concentrates will produce performance equivalent to that observed with milk protein and may be used to replace milk protein when economic circumstances allow.

TABLE 3.1

COMPOSITION OF EXPERIMENTAL DIETS
FED DURING PERIOD 1 (2 WEEKS)

	Diets[a,b]						
Ingredient	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM
Soybean meal, 50%	-	-	-	-	-	-	24.12
Soy protein concentrate I[c]	-	-	-	25.09	-	-	-
Soy protein concentrate II[d]	-	-	-	-	25.09	-	-
Soy protein concentrate III[e]	-	-	-	-	-	25.09	-
Isolated soy protein I[f]	-	20.29	-	-	-	-	-
Isolated soy protein II[g]	-	-	20.29	-	-	-	-
Dried skim milk	40.00	-	-	-	-	-	-
Whey, dried whole	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Lactose	-	20.62	20.62	20.62	20.62	20.62	20.62
Cerelose	7.31	4.77	4.77	-	-	-	0.27
Soybean oil	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Lysine, HCl	.19	-	-	.04	.04	.04	.44
DL-Methionine	.16	.30	.30	.24	.24	.24	.35
Tryptophan	-	-	-	-	-	-	.03
Threonine	-	-	-	-	-	-	.09
Lecithin	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Apralan[h]	.10	.10	.10	.10	.10	.10	.10
Calcium carbonate	-	.53	.53	.50	.50	.50	.39
Dicalcium phosphate	-	1.15	1.15	1.17	1.17	1.17	1.35
Vit. TM premix[i]	.94	.94	.94	.94	.94	.94	.94
Salt	.30	.30	.30	.30	.30	.30	.30
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 3.1 (Continued)

[a]As fed basis.
[b]DSM: dried skim milk protein diet; ISPI: Isolated soy protein (soluble) diet; ISPII: Isolated soy protein (insoluble) diet; SPCI, II, and III: Soy protein concentrate diet; SBM: soybean meal diet.
[c]Promocon-plus, Central Soya, Fort Wayne, IN.
[d]Promine, Central Soya, Fort Wayne, IN.
[e]Promocalf, Central Soya, Fort Wayne, IN.
[f]PP-620, Protein Technologies International.
[g]PP-HD-90, Protein Technologies International.
[h]Contained 75 g Apramycine per lb.
[i]Supplied 8,800 IU vitamin A, 880 IU vitamin D, 37 IU vitamin E, 44 mg pantothenic acid, 59 mg niacin, 8.8 mg riboflavin, 7.3 mg menadione sodium bisulfate, 0.04 mg vitamin B12, 3 mg biotin, 6 mg pyridoxine, 2 mg folic acid, 10 mg thiamin, 880 mg choline chloride, 0.2 mg selenium, 0.06 g manganese, 0.2 g zinc, 0.2 g iron, 0.2 g copper, 0.2 g magnesium, 1.0 g potassium and 0.4 mg iodine, per kg of feed.

TABLE 3.2

NUTRIENT COMPOSITION OF DIETS FED DURING PERIOD 1 (2 WEEKS)

	Diet[a]						
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM
Calculated analysis (%)							
Crude protein	19.20	23.37	23.37	21.23	21.23	21.23	16.50
Calcium	.90	.90	.90	.90	.90	.90	.90
Phosphorus	.71	.70	.70	.70	.70	.70	.70
Lactose	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Lecithin	.30	.30	.30	.30	.30	.30	.30
Lysine	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Tryptophan	.25	.28	.28	.28	.28	.28	.27
Threonine	1.00	1.02	1.02	1.06	1.06	1.06	1.00
Met+Cys	.88	.88	.88	.88	.88	.88	.88
ME (Kcal/kg)	3570.6	3543.9	3543.9	3520.2	3520.2	3520.2	3529.5
Actual analysis							
Crude protein (N X 6.25)	19.36	22.76	22.84	22.77	21.53	21.32	17.73

[a]As fed basis.

TABLE 3.3

PROTEIN AND AMINO ACID COMPOSITION OF DIETARY PROTEIN SOURCES

	Diet[a]						
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM
Crude protein, %	35.77	89.55	88.60	67.43	65.77	68.07	50.03
Amino acids, g/16 g N							
Essential							
Arginine	3.11	7.43	7.05	7.07	7.28	7.05	7.04
Histidine	2.32	2.52	2.41	2.38	2.57	2.45	2.50
Isoleucine	4.30	4.30	4.00	4.03	4.36	4.07	4.02
Leucine	9.25	8.16	8.04	7.88	7.89	7.52	7.48
Lysine	5.97	6.15	6.07	6.10	6.22	6.04	6.07
Methionine	2.47	1.02	1.13	1.16	1.16	1.10	1.14
Phenylalanine	4.00	5.26	5.13	5.03	5.11	5.07	4.97
Threonine	4.69	3.98	3.80	3.85	4.07	3.92	3.98
Valine	6.19	4.40	4.37	4.20	4.58	4.26	4.24

TABLE 3.3 (Continued)

	Diet[a]						
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM
Nonessential							
Alanine	3.76	4.27	4.10	4.09	4.30	4.13	4.16
Aspartic acid	7.89	11.38	11.04	10.98	11.30	10.93	10.98
Glutamic acid	18.72	19.41	18.63	18.86	18.51	18.02	18.01
Cystine	1.13	1.04	1.00	1.06	1.02	1.18	1.22
Glycine	2.77	4.14	4.05	4.00	4.20	4.03	4.08
Proline	9.34	5.33	5.14	5.04	5.14	5.02	4.94
Serine	5.12	5.36	5.22	5.09	5.22	5.04	5.12
Tyrosine	3.59	3.69	3.43	3.32	3.47	3.31	3.28

[a]For explanation of diet code names, see Table 1.

TABLE 3.4

PROTEIN AND AMINO ACID COMPOSITION OF EXPERIMENTAL DIETS[a]

	Diet[a]						
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM
Crude protein, %	19.36	22.76	22.84	22.77	21.53	21.32	17.73
Amino acids, %							
Essential							
Arginine	.96	1.28	1.27	1.17	1.22	1.21	1.07
Histidine	.51	.59	.59	.56	.59	.57	.49
Isoleucine	.82	.99	.95	.94	.98	.95	.80
Leucine	1.59	1.79	1.75	1.64	1.68	1.63	1.58
Lysine	1.48	1.53	1.52	1.48	1.57	1.56	1.54
Methionine	.51	.51	.48	.44	.47	.45	.46
Phenylalanine	.78	1.00	.99	.91	.90	.91	.76
Threonine	.93	1.04	1.03	1.00	1.04	1.02	.94
Valine	.94	1.00	.96	.96	.99	.96	.86

TABLE 3.4 (Continued)

Item	Diet[a]						
	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM
Nonessential							
Alanine	.71	1.01	1.01	.94	.84	.95	.79
Aspartic acid	1.38	2.38	2.36	2.23	2.31	2.25	1.73
Cystine	.20	.28	.29	.26	.27	.32	.31
Glutamic acid	3.19	3.92	3.89	3.52	3.66	3.55	2.84
Glycine	.44	.76	.76	.72	.74	.73	.69
Proline	1.34	1.18	1.12	1.05	1.06	1.03	.92
Serine	.90	1.11	1.10	1.01	1.05	1.02	.91
Tyrosine	.67	.73	.72	.68	.70	.68	.62

[a]Dry matter basis.
[b]For explanation of diet code names, see Table 1.

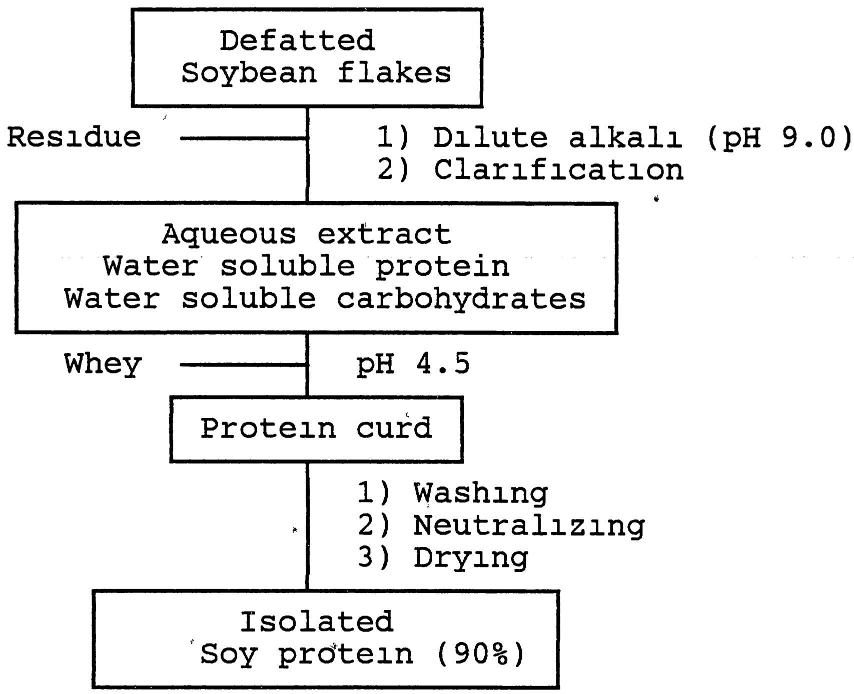

Figure 1. Outline of Process for the Production of Isolated soy protein.

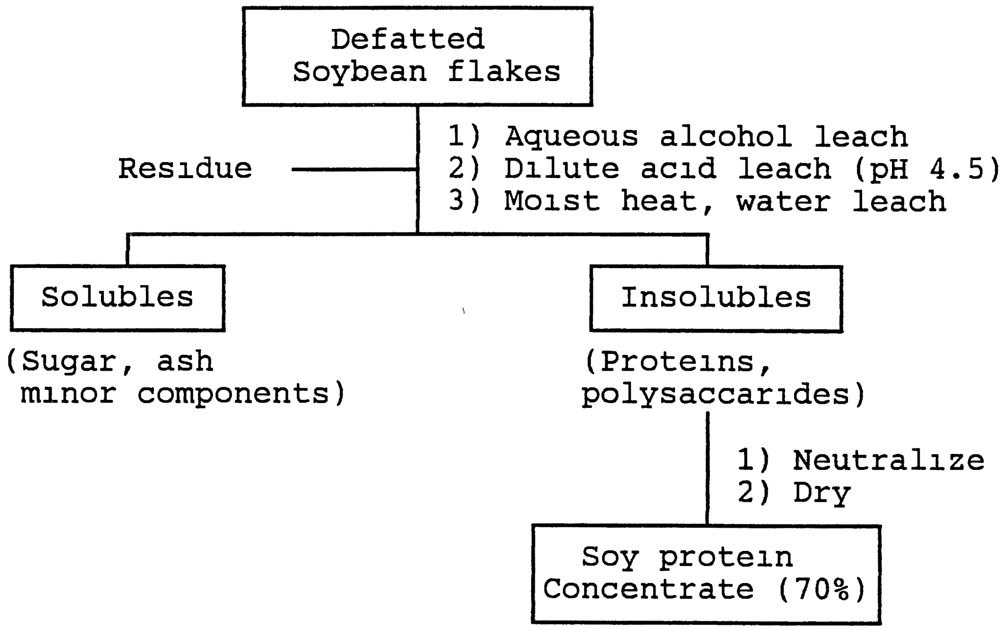

Figure 2. Processes for Preparing Soy protein concentrates.

TABLE 3.5

TRYPSIN INHIBITOR ACTIVITY OF PROTEIN SOURCES AND DIETS[a]

	Diet[b]				
Item	ISPI	ISPII	SPCI	SPCII	SPCIII
Crude protein, %	89.55	88.60	67.21	65.77	68.07
Trypsin inhibitor[c] (units/g product)	5.90	3.45	5.63	5.58	2.50
Trypsin inhibitor (units/g diet)	1.20	.70	1.41	1.40	.63

[a]As fed basis.
[b]For explanation of diet code names, see Table 1.
[c]Trypsin inhibitor values of soybean proteins were provided by Central Soya.

TABLE 3.6

MINERAL ANALYSIS AND PHYSICAL PROPERTIES
OF PROTEIN SOURCE

	Protein	
Items	ISP	SPC
Crude protein, % (N X 6.25)	91.50	65.50
Mineral analysis		
Moisture, %	5.50	7.25
Calcium	.20	.26
Phosphorus	.80	-
Potassium	.10	2.43
Sodium	1.10	.02
Physical properties		
pH	7.00	7.00
Color	Cream	Cream
Particle size	90% through 100 mesh	
Salmonella	Negative	Negative

TABLE 3.7

COMPOSITION OF EXPERIMENTAL DIETS
FED DURING PERIOD 2

Ingredients	% of diet[a]
Yellow corn	67.300
Soybean meal (44%)	28.500
Dicalcium phosphate	1.950
Calcium carbonate	.900
Vitamin TM premix[b]	.375
Lysine, HCl	.150
Salt	.400
Copper sulfate	.075
Banmith (pyrantel tartrate - 48 g/lb)	.100
Mecadox - 10 (Carbadox - 10 g/lb)	.250
	100.00
Calculated composition of diet	
ME (Kcal/kg)	3150.620
Lysine, %	1.100
Crude protein, %	18.480
Threonine, %	.750
Tryptophan, %	.220
Met + Cys, %	.610
Calcium, %	.850
Phosphorus,%	.700
Actual analysis	
Crude protein (N X 6.25)	20.600

[a]As fed basis.
[b]Supplied 8,800 IU vitamin A, 880 IU vitamin D, 37 IU vitamin E, 44 mg pantothenic acid, 50 mg niacin, 8.8 mg riboflavin, 7.3 mg menadione sodium bisulfate, .04 mg vitamin B_{12}, 880 mg choline chloride, .2 mg selenium, .06 g manganese, .2 g zinc, .2 g iron, .2 g copper, .4 mg iodine.

TABLE 3.8

TYPICAL COMPOSITION OF SOYBEANS AND SOYBEAN PRODUCTS[1]

Item	Crude protein (N X 6.25) (%)	Crude fat (%)	Total carbo-hydrates[2] (%)	Ash (%)	Crude fiber (%)
Whole soybean	42	20	35	5.0	5.5
Defatted soy flour	54	1.0	38	6.0	3.5
Soy protein concentrate	70	1.0	24	5.0	3.5
Isolated soy protein	92	.5	2.5	4.5	.5

[1]Moisture free basis.
[2]Includes crude fiber.

TABLE 3.9

THE EFFECT OF PROTEIN SOURCE ON ADG IN PERIOD 1 (kg/d)[a]

	Diet[b]							
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM	SEM
No. of pigs	10	10	10	10	10	10	11	
d 0 - 7	.20[c]	.21[c]	.20[c]	.19[c]	.18[c]	.17[c]	.10[d]	.04
d 7 - 14	.31[cd]	.35[d]	.39[d]	.37[d]	.36[d]	.36[d]	.29[c]	.05
d 0 - 14	.27[e]	.28[e]	.29[e]	.28[e]	.27[e]	.26[e]	.19[f]	.04

[a]LS means.
[b]For explanation of diet code names, see Table 1.
[cd]Means in the same row with different superscripts differ (P<.01).
[ef]Means in the same row with different superscripts differ (P<.05).

TABLE 3.10

THE EFFECT OF PROTEIN SOURCE ON ADG IN PERIOD 2 (kg/d)[a]

	Diet[b]							
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM	SEM
No. of pigs	10	10	10	10	10	10	11	
d 14 - 21	.37	.38	.41	.39	.40	.41	.43	.07
d 14 - 35	.53	.55	.54	.54	.55	.55	.54	.03

[a]LS means.
[b]For explanation of diet code names, see Table 1.

TABLE 3.11

THE EFFECT OF PROTEIN SOURCE ON FEED EFFICIENCY (G:F)[a]

	Diet[b]							
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM	SEM
No. of pigs	10	10	10	10	10	10	11	
d 0 - 7	.85[c]	.86[c]	.86[c]	.83[c]	.79[c]	.79[c]	.66[d]	.08
d 7 - 14	.75[e]	.79[e]	.83[e]	.79[e]	.79[e]	.78[e]	.66[f]	.05
d 0 - 14	.80[g]	.83[g]	.85[g]	.81[g]	.79[g]	.79[g]	.66[h]	.08
d 14 - 35	.62	.63	.63	.62	.63	.63	.63	.02

[a]LS means kg gain/kg feed.
[b]For explanation of diet code names, see Table 1.
[cdefgh]Means in the same row with different superscripts differ ($P<.05$).

TABLE 3.12

THE EFFECT OF PROTEIN SOURCE ON FEED INTAKE DURING PERIOD 1 (kg/d)[a]

	Diet[b]							
Item	DSM	SPI	ISPII	SPCI	SPCII	SPCIII	SBM	SEM
No. of pigs	10	10	10	10	10	10	11	
d 0 - 7	.25[c]	.24[c]	.24[c]	.22[c]	.23[c]	.22[c]	.15[d]	.04
d 7 - 14	.46	.45	.48	.48	.46	.46	.43	.06
d 0 - 14	.36	.35	.36	.35	.35	.34	.29	.08

[a]LS means.
[b]For explanation of diet code names, see Table 1.
[cd]Means in the same row with different superscripts differ (P<.05).

TABLE 3.13

THE EFFECT OF PROTEIN SOURCE ON FEED INTAKE DURING PERIOD 2 (kg/d)[a]

	Diet[b]							
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM	SEM
No. of pigs	10	10	10	10	10	10	11	
d 14 - 21	.62	.65	.68	.63	.69	.70	.66	.09
d 21 - 28	.86	.92	.87	.89	.88	.91	.84	.09
d 28 - 35	1.11	1.14	1.10	1.13	1.13	1.14	1.12	.05
d 14 - 35	.86	.90	.88	.88	.90	.92	.87	.07

[a]LS means.
[b]For explanation of diet code names, see Table 1.

TABLE 3.14

THE EFFECT OF PROTEIN SOURCE ON
PIG WEIGHT (kg)[a]

Item	Diet[b]							
	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM	SEM
No. of pigs	10	10	10	10	10	10	11	
In. Wt.	5.00	5.00	4.97	5.00	4.97	4.97	4.96	
Week 1	6.42^{c}	6.46^{c}	6.39^{c}	6.32^{c}	6.23^{c}	6.15^{c}	5.63^{d}	.32
Week 2	8.82^{e}	8.93^{e}	9.14^{e}	8.96^{e}	8.75^{e}	8.70^{e}	7.67^{f}	.45
Week 3	11.39	11.56	12.00	11.69	11.56	11.58	10.70	.62
Week 4	15.35	15.94	16.05	15.83	15.74	15.81	14.88	1.19
Week 5	19.86	20.52	20.53	20.46	20.29	20.36	19.19	1.18

[a]LS means.
[b]For explanation of diet code names, see Table 1.
[cdef]Means in the same row with different superscripts differ ($P<.05$).

TABLE 3.15

THE EFFECT OF PROTEIN SOURCE ON AVERAGE DAILY GAIN (ADG) AND AVERAGE DAILY FEED INTAKE (ADFI) OVERALL PERIOD (5 WK)

	Diet[a]						
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM
Pigs per treatment, No.[b]	10	10	10	10	10	10	11
Initial age, d	20.9	21.0	21.0	20.9	20.9	21.0	21.0
Initial weight, kg	5.00	5.00	4.97	5.00	4.97	4.97	4.96
Final weight, kg	19.86	20.52	20.53	20.46	20.46	20.36	19.19
ADFI, g	660	680	670	670	680	690	640
ADG, g	425	443	445	442	439	441	407

[a]For explanation of diet code names, see Table 1.
[b]One pig on the DSM diet was removed because of feed refusal.

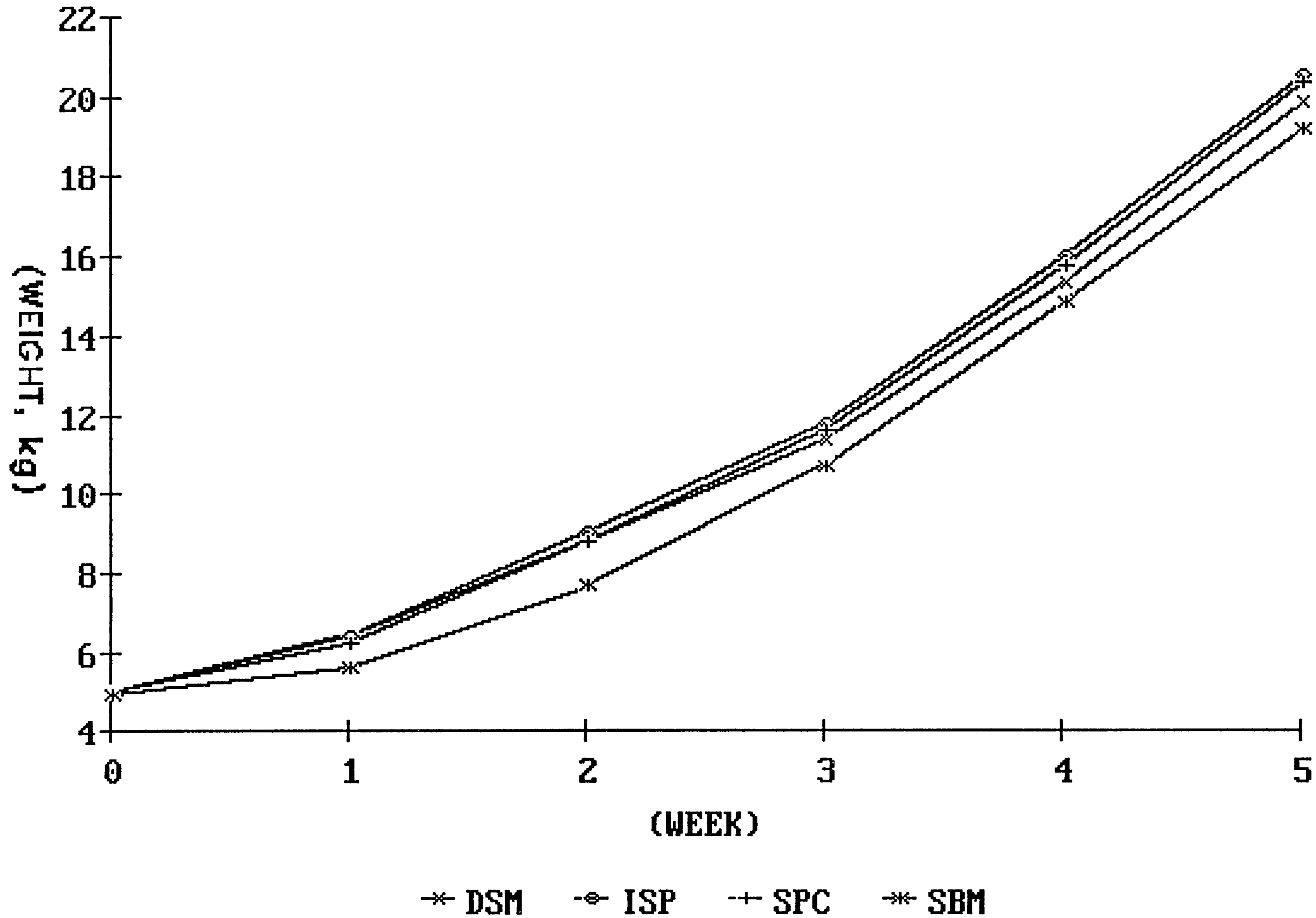

Figure 3. LS Means of Pig Weight by Week

TABLE 3.16

APPARENT AVAILABILITY OF DRY MATTER AND ASH MEASURED OVER THE TOTAL DIGESTIVE TRACT FOR EARLY WEANED PIGS AT WEEK ONE AFTER WEANING

	Diet[b]							
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM	SEM
Pigs per treatment, No.[b]	10	10	10	10	10	10	11	
Initial age, d	20.90	21.00	21.00	20.90	20.90	21.00	21.00	
Initial weight, kg	5.00	5.00	4.97	5.00	4.97	4.97	4.96	
Weight at 28 d, kg	6.42	6.46	6.39	6.32	6.23	6.15	5.63	
Apparent digestibility:								
Dry matter, %	92.37[c]	91.08[c]	91.00[c]	90.43[c]	90.48[c]	90.22[c]	80.39[d]	2.2
Ash, %	87.55	86.10	85.70	85.70	85.31	85.47	84.90	2.8

[a]For explanation of diet code names, see Table 1.
[b]One pig on the DSM diet was removed because of feed refusal.
[cd]Means in the same row with different superscripts differ ($P<.05$).

TABLE 3.17

APPARENT AVAILABILITY OF DRY MATTER AND ASH MEASURED OVER THE TOTAL DIGESTIVE TRACT FOR EARLY WEANED PIGS AT WEEK TWO AFTER WEANING

	Diet[a]							
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM	SEM
Pigs per treatment, No.[b]	10	10	10	10	10	10	11	
Initial age, d	20.90	21.00	21.00	20.90	20.90	21.00	21.00	
Initial weight, kg	5.00	5.00	4.97	5.00	4.97	4.97	4.96	
Weight at 35 d, kg	8.82	8.93	9.14	8.96	8.75	8.70	7.67	
Apparent digestibility:								
Dry matter, %	92.64[c]	92.43[c]	92.15[c]	91.98[c]	91.48[c]	91.24[c]	82.95[d]	1.7
Ash, %	87.93	85.76	86.84	85.70	85.42	86.70	84.70	3.3

[a]For explanation of diet code names, see Table 1.
[b]One pig on the DSM diet was removed because of feed refusal.
[cd]Means in the same row with different superscripts differ (P<.05).

TABLE 3.18

DIFFERENCE BETWEEN PERIOD (WEEK TWO VS WEEK ONE)
IN NUTRIENT AVAILABILITY DETERMINED
OVER TOTAL DIGESTIVE TRACT[a]

	Diet[b]							
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM	SEM
Difference								
Dry matter[e]	.27[c]	1.35[cd]	1.15[cd]	1.55[cd]	1.00[cd]	1.02[cd]	2.56[d]	1.56
Ash	.38	-.34	1.14	.00	.11	1.23	-.20	1.59

[a]Differences obtained by subtraction of availability estimate of 1st week from availability of 2nd week after weaning.
[b]For explanation of diet code names, see Table 1.
[cd]Means in the same row with different superscripts differ ($P<.05$).
[e]DM availability of pigs fed the SBM diet between 1st week and 2nd week differ ($P<.05$).

TABLE 3.19

APPARENT AVAILABILITY OF NITROGEN AND AMINO ACIDS
MEASURED OVER THE TOTAL DIGESTIVE TRACT
FOR 28 DAY OLD PIGS[a]

	Diet[b]							
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM	SEM
Pigs per treatment, No.	10	10	10	10	10	10	11	
Initial age, d	20.9	21.0	21.0	20.9	20.9	21.0	21.0	
Initial weight, kg	5.00	5.00	4.97	5.00	4.97	4.97	4.96	
Nitrogen, %	92.61[d]	91.19[d]	90.71[d]	91.05[d]	90.65[d]	90.37[d]	80.06[e]	2.3
Amino acids, %								
Essential								
Arginine[c]	87.3	90.1	90.3	89.1	88.4	88.7	78.3	3.0
Histidine[c]	84.2	86.3	86.7	86.0	85.9	85.7	79.4	1.2
Isoleucine[c]	87.8	85.7	85.9	85.0	86.2	85.2	78.7	2.8
Leucine[c]	88.4	86.8	86.9	87.0	86.2	86.3	79.2	2.8
Lysine[c]	91.7[d]	87.0[e]	86.9[e]	87.2[e]	86.9[e]	86.7[e]	79.1	1.8
Phenylalanine[c]	89.4[d]	84.2[e]	84.1[e]	83.9[e]	84.4[e]	84.0[e]	79.2	1.1
Threonine[c]	81.9	80.4	80.7	80.4	81.0	80.2	73.4	1.8
Valine[c]	87.2	85.0	85.1	84.9	84.8	84.5	78.1	2.8
AVG.	87.2[f]	85.7[f]	85.8[f]	84.9[f]	85.5[f]	84.6[f]	78.2[g]	2.7

TABLE 3.19 (Continued)

Item	Diet[b]							
	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM	SEM
Nonessential								
Alanine[c]	83.2	81.7	80.9	81.4	80.3	79.9	69.9	3.4
Aspartic acid[c]	82.6	84.1	83.7	84.3	82.7	81.8	70.4	2.6
Glutamic acid[c]	85.9[d]	82.4[e]	83.0[e]	81.9[e]	82.2[e]	82.0[e]	71.3	1.8
Glycine[c]	81.3	80.9	80.4	79.7	79.2	78.3	70.2	3.2
Proline[c]	90.5[d]	86.7[e]	85.9[e]	87.0[e]	85.8[e]	86.2[e]	74.2	1.2
Serine[c]	80.6	79.7	78.9	78.4	79.1	77.9	69.2	3.0
Tyrosine[c]	90.7	89.2	88.7	89.0	87.7	87.9	80.0	3.2
AVG.	85.0[f]	83.5[f]	83.1[f]	83.1[f]	82.4[f]	82.0[f]	72.2[g]	3.1

[a]One pig on the DSM diet was removed because of feed refusal.
[b]For explanation of diet code names, see Table 1.
[c]SBM differs from other diets (P<.01).
[de]Means in the same row with different superscripts differ (P<.05).
[fg]Means in the same row with different superscripts differ (P<.01).

TABLE 3.20

APPARENT AVAILABILITY OF NITROGEN AND AMINO ACIDS MEASURED OVER THE TOTAL DIGESTIVE TRACT FOR 35 DAY OLD PIGS[a]

	Diet[b]							
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM	SEM
Pigs per treatment, No.	10	10	10	10	10	10	11	
Initial age, d	20.9	21.0	21.0	20.9	20.9	21.0	21.0	
Initial weight, kg	5.00	5.00	4.97	5.00	4.97	4.97	4.96	
Nitrogen, %	92.60[d]	92.27[d]	91.98[d]	92.21[d]	91.75[d]	92.08[d]	82.08[e]	1.3
Amino acids, %								
Essential								
Arginine[c]	87.7	90.2	90.7	90.2	89.1	88.9	80.4	1.8
Histidine	84.7	86.9	87.0	86.2	86.3	86.2	83.2	2.3
Isoleucine[c]	87.7	86.2	87.0	85.4	86.9	86.9	80.7	2.4
Leucine[c]	88.2	87.0	88.2	86.7	87.1	88.9	82.2	1.8
Lysine[c]	91.9[d]	88.7[e]	87.6[e]	88.4[e]	87.8[e]	87.0[e]	82.6	1.9
Phenylalanine	87.7[d]	85.2[de]	85.9[de]	85.3[de]	85.2[de]	85.0[de]	82.1[e]	3.9
Threonine[c]	82.0	83.4	82.9	83.1	82.7	83.0	75.5	1.4
Valine	86.2[d]	80.4[e]	79.9[e]	81.7[e]	81.2[e]	79.9[e]	75.4[f]	1.8
AVG.	87.5[g]	86.0[g]	86.2[g]	85.9[g]	85.8[g]	85.6[g]	80.3[h]	1.9

TABLE 3.20 (Continued)

	Diet[b]							
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM	SEM
Nonessential								
Alanine[c]	82.9	82.0	81.4	81.7	81.0	80.2	71.0	2.8
Aspartic acid[c]	82.5	84.2	83.1	84.2	82.6	82.0	72.2	2.3
Glutamic acid[c]	87.2[d]	83.1[e]	83.5[e]	82.1[e]	82.7[e]	83.2[e]	79.9	1.6
Glycine[c]	81.7	81.2	81.5	80.2	81.0	79.7	72.2	2.2
Proline[c]	90.9[d]	87.9[e]	86.2[e]	87.3[e]	87.1[e]	87.4[e]	75.6	1.9
Serine[c]	85.2	84.1	83.4	83.2	83.7	83.5	76.3	2.1
Tyrosine[c]	91.0	89.9	89.2	89.4	88.2	88.7	83.0	1.9
AVG.	85.9[g]	84.6[g]	84.0[g]	84.0[g]	83.8[g]	83.5[g]	75.7[h]	2.5

[a]One pig on the DSM diet was removed because of feed refusal.
[b]For explanation of diet code names, see Table 1.
[c]SBM differs from other diets (P<.01).
[de]Means in the same row with different superscripts differ (P<.05).
[gh]Means in the same row with different superscripts differ (P<.01).

TABLE 3.21

DIFFERENCE OF APPARENT FECAL AMINO ACID AVAILABILITY ESTIMATES BETWEEN 2 PERIODS (WEEK TWO VS WEEK ONE) IN EARLY WEANED PIGS[a]

	Diet[b]							
Item	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM	SEM
Nitrogen, %	-.01[c]	1.08[d]	1.27[d]	1.16[d]	1.10[d]	1.71[d]	2.02[d]	.95
Amino acids, %								
Essential								
Arginine	.4	.1	.4	1.1	.7	.2	2.1	
Histidine	.5	.6	.3	.2	.4	.5	3.8	
Isoleucine	-.1	.5	1.1	.4	.7	1.7	2.0	
Leucine	-.2	.2	1.3	-.3	.9	2.6	3.0	
Lysine	.2	1.7	.7	1.2	.9	.3	3.5	
Phenylanine	-.7	1.0	1.8	1.4	.8	1.0	2.9	
Threonine	.1	3.0	2.2	2.7	1.7	2.8	2.1	
Valine	-1.0	1.5	1.5	1.5	1.9	1.3	2.0	
AVG[f].	-.8[c]	1.08[d]	1.16[d]	1.03[d]	1.00[d]	1.30[de]	2.10[e]	.85

TABLE 3.21 (Continued)

Item	Diet[b]							
	DSM	ISPI	ISPII	SPCI	SPCII	SPCIII	SBM	SEM
Nonessential								
Alanine	-.3	.3	.5	.3	.7	.3	1.1	
Aspartic acid	-.1	.1	-.6	-.1	-.1	.2	1.8	
Glutamic acid	1.3	.7	.5	.3	.5	1.2	3.6	
Glycine	.4	.3	1.1	.5	1.8	1.4	2.0	
Proline	.4	1.2	.3	.3	1.3	1.2	1.4	
Serine	4.6	4.4	4.5	4.8	4.6	5.6	7.1	
Tyrosine	.3	.7	.5	.4	.5	.8	3.0	
AVG[f].	.90[c]	1.10[c]	.90[c]	.90[c]	1.40[c]	1.50[c]	3.50[d]	.7

[a]One pig on the DSM diet was removed because of feed refusal.
[b]For explanation of diet code names, see Table 1. Differences were obtained by subtraction of the apparent fecal availability estimate of 2nd wk after weaning from the fecal availability estimate of 1st wk after weaning.
[cde]Means in the same row with different superscripts differ (P<.05).
[f]EAA and NEAA availabilities of pigs fed the SBM between 1st and 2nd week differ (P<.05).

CHAPTER IV

AMINO ACID AVAILABILITY OF VARIOUS PROTEIN SOURCES IN EARLEY WEANED PIGS

Summary

A 4x4 Latin square trial was conducted using four early weaned gilts fitted with a simple ileal T-cannula to determine the effect of protein source on protein and amino acid availability. The availability of dry matter (DM), ash, nitrogen (N) and amino acids (AA) in 25 day old pigs fed either dried skim milk (DSM), isolated soy protein (ISP), soy protein concentrate (SPC) or soybean meal (SBM) diets were determined at both the ileum and in the total digestive tract. The pigs were fed semi-purified diets formulated to contain 22% crude protein. The availability of dry matter, nitrogen and overall essential amino acids and nonessential amino acids both at the terminal ileum and over the total digestive tract of early weaned pigs was higher (P<.01) in pigs fed the DSM, ISP and SPC diets than in those fed the SBM diet. The ileal availability of nitrogen and all amino acids except glutamic acid significantly increased with increasing piglet age. Of limiting amino acids, lysine and threonine disappeared to a large extent in the large intestine. Availabilities both at the ileum and total digestive tract for lysine and valine for early weaned pigs fed the DSM diet was higher (P<.01) than those fed any of the soybean protein diets. Availabilities of all other essential amino acids were similar among DSM, ISP and SPC diets. The ileal and fecal availabilities for essential amino acids were higher in the older pigs with an average availability of 84.0, 83.9 88.2 and 89.2% and 87.0, 87.3, 91.8 and 94.2% from 1st week to the 4th week experimental period, respectively. Availability values over the total digestive tract were higher than values estimated at the ileum, indicating a net disappearance of both N and AA in the hindgut. This study suggest that low amino acid availability of the the first limiting amino acid, lysine, may limit performance of pigs fed a soybean meal diet.

(Key words: Swine, Early weaned pigs, Soybean meal, Amino acid availability, Ileal cannulation).

Introduction

Weaning as early as 18 day often is desirable for swine producers to maximize efficiency. However, early weaning commonly results in low feed intake, poor feed conversion, intestinal malabsorption and weight losses in the early weeks post-weaning. Weaning causes changes in the morphology of the small intestine of pigs (Kenworthy and Allen, 1966; Kenworthy, 1976; Hampson, 1986a and 1986b; Miller et al., 1986). During the first week postweaning, the small intestinal villi decrease in height which is an indication of enterocyte destruction, the lamina propria increases in depth which is an indication of crypt depth, cellular proliferation and maturity of villus enterocytes. This results in a decreased absorptive area which has been implicated as an important factor in postweaning diarrhea. Additionally, enzyme activities of brush border membrane decrease during the first week postweaning (Hampson and Kidder, 1986; Kenworthy, 1976) and may contribute to the intestinal malabsorption and subsequent poor performance of early weaned pigs. The reduced performance accompanying early weaning has been well documented (Bayley and Carlson, 1970; Kornegay et al., 1974; Campbell, 1976; Okai et al., 1981) and is associated with a reduced feed intake and little or no weight gain. Early weaned pigs experience a longer postweaning growth depression and higher mortality rate (Leibbrandt et al., 1975; Lecce et al., 1979) than those weaned later.

Several studies have suggested that nutritional factors may influence postweaning performance in early weaned pigs (Lewis et al., 1955; Combs et al., 1960; Maner et al., 1961; Lennon et al., 1971; Coalson et al., 1972; Ostermer et al., 1973; Henry et al., 1976). A large number of studies have shown that performance of early weaned pigs is slower with soybean protein diets than with milk protein diets (Hays et al., 1959; Maner et al., 1961; Combs et al., 1963; Pond et al., 1971; Leibholz, 1982; Wilson and Leibholz, 1981 a,b,c).

This can be explained partially by lower digestibility of the nitrogen in the soybean proteins and incomplete hydrolysis of soybean proteins in the small intestine.

It is of interest to determine if soybean proteins can be improved by processing for young pigs. Alkali or acid treatment of soybean protein has been shown to improve pig performance. Isolated soy protein and soy protein concentrate now available may be improved over those used previously.

Knowledge of differences in amino acid availability, particularly for lysine, should allow formulation of early weaned pig diets on an available amino acid basis.

Sewell and West (1965) reported that lactose supplementation of an isolated soy protein diet produced higher daily gain and higher gain to feed ratios for pigs of 21 days of age than did an isolated soy protein diet without lactose. Work with rat (Forsum, 1975) also indicated that lactose supplementation improved the biological value of readily digestible protein sources in the diet.

Several studies have shown that protein sources vary not only in amino acid content but also in amino acid availability as measured either at the ileum or in fecal samples of growing-finishing pigs (Homes et al., 1974; Ivan and Farrell, 1976; Sauer et al., 1977; Tanksley and Knabe, 1980; Taverner and Farrell, 1981; Jorgensen et al., 1984). However, studies in the early weaned pig, where the effects of protein source may be more critical have not been tested adequately. In addition, nutrient digestibility between the ileum and feces for early weaned pigs has received limited study. This study was conducted to determine the biological availability of dry matter, nitrogen and individual amino acids in milk and soybean proteins fed to ileally cannulated early weaned pigs.

Materials and Methods

Four yorkshire gilts were surgically fitted with a simple T-cannula located in the distal ileum approximately 5 cm from the ileocecal junction. The material used to make this single piece cannula was an acetal homopolymer resin that provides a rigid lightweight yet extremely durable plastic. Pigs were removed from the sow at 18 days of age at which time the cannulas were surgically installed. Cannula design and surgical techniques were used by methods suggested by Walker (1984). Immediately following surgery, pigs were returned to the sow where they remained with the rest of the litter for a 5 day convalescence period. Creep feed and water were available at all times during the convalescent period. After recovery, the pigs were removed to an environmentally controlled feeding room where they were housed in individual elevated metal pens measuring .7 by 1.0 m. Temperature in the feeding room was maintained between 27^{0}c and 32^{0}c for the duration of the trial. After a 2 day adaptation period the pigs at 25 days of age were started on a 4 x 4 Latin square trial.

Dietary treatments consisted of one milk and three soybean protein sources in semi-purified cornstarch-cerelose based diets (Table 4.1). Protein sources included dried skim milk (DSM), isolated soy protein (ISP), Soy protein concentrate (SPC) and soybean meal (SBM). Twenty-two percent crude protein diets were formulated to exceed the NRC (1988) requirement for crude protein for the 5 to 10 kg pigs by 10% such that no single AA should be limiting. Diets were supplemented with vitamins and minerals to provide completely balanced diets for this age and weight of pig. Chromic oxide was added as an indigestible marker to allow for availability determinations. Each pig was fed a measured quantity of feed twice daily at 08:00 and 20:00 hour and allowed continuous access to the feed for a 1 hour period after which all uneaten feed was removed. All uneaten and wasted feed was collected, dried and weighed so daily feed intake for each pig could be monitored. Water was available at all times.

Each of the four 7-d experimental periods consisted of a 4-d adjustment period followed by a 3-d collection period. Ileal samples were collected continuously on each collection day, beginning one hour after the morning feeding and continuing until either 50 g of wet samples was collected for each pig or until feeding time of the evening meal. Samples were collected in vinyl bags suspended from the cannula. Bags containing samples were changed at a maximum of 1 hour intervals. After removal from the pig all digesta samples were immediately frozen and stored at -20^{0}C. Ileal samples collected over the 3 collection days of each period were composited by treatment prior to lyophilyzation and grinding for laboratory analysis. Dry matter, nitrogen and ash content of feed, ileum and fecal samples was determined according to AOAC (1980) methods. Chromic oxide content was determined as described by Williams et al (1962). Amino acid analyses were determined by ion-exchange chromatography using a modified Beckman model 6300 amino acid analyzer. Acid hydrolysis was conducted under nitrogen reflux in 6 N HCL for 22 h. The ileal and fecal DM, ash, N and AA availabilities were calculated using chromic oxide as an indigestible marker.

The data for each response criteria were analyzed as a 4x4 Latin square design by least squares analysis of variance. The standard error reported for each period is the mean of the standard errors of all treatments. Orthogonal polynomials were used to test for linear, quadratic and cubic effects for the different periods. The model included the main effects of pig, period and treatment.

Results and Discussion

Protein and amino acid composition of the dietary protein sources and the complete diets are shown in table 4.3 and 4.4. Dried skim milk was higher in methionine, valine and leucine content but lower in lysine and arginine when compared to other protein sources. The three soybean protein diets were similar in essential amino acid content but higher in all essential amino acids except methionine, valine and isoleucine than the dried skim milk diet. Lysine, sulfur-containing amino acids, tryptophan and threonine are the amino acids that can be considered to be more important amino acids in practical diet formulation, as these are often first-, second-, or third-limiting in many feedstuffs and therefore, are of the most interest.

Availabilities of dry matter and ash from various protein sources at both the terminal ileum and over the total digestive tract are shown in table 4.5. DM availability at both sites was lower (P<.01) in pigs fed SBM than in pigs fed all other protein sources; DM availability among pigs fed the DSM, ISP and SPC diets was similar. The ileal DM availability estimates of 84.72 and 83.57% for the DSM and ISP diets reported in this study were similar to the values 82.6 and 82.5% for pigs fed milk and isolated soy protein diets, respectively reported by Wilson and Leibholz (1981b). The ileal DM availability estimate of 71.8% for the soybean meal diet reported in this study was slightly higher than that (64.4%) reported by Wilson and Leibholz (1981b). The dry matter availability estimates in pigs fed DSM and ISP diets obtained over the total digestive tract reported here were lower than those previously reported by Wilson and Leibholz (1981b). The reason for this low fecal DM availability is unknown because the dry matter availability estimates obtained from terminal ileum are similar to values reported by these same authors. Dry matter disappearance from the hindgut ranged from 10.5% for SBM to 5.5% for DSM which may be at least to some extent a reflection of the higher fiber content of SBM and the high digestibility of nutrients in DSM. The ash availability both at the terminal ileum and for the total digestive tract was similar for all the protein sources. Ash availability for the total digestive tract was higher (P<.05) than estimates obtained at the ileum.

The ileal availability of nitrogen, essential amino acid and nonessential amino acids was lower (P<.01) in pigs fed the SBM diet than in those fed all other protein sources (Table 4.6). The average ileal availability of essential amino acids by pigs fed the SBM diet was 79.2% compared to 89.3, 88.5 and 88.4% for those fed the DSM, ISP and SPC diets, respectively. The ileal availability of lysine and valine was higher (P<.05) in pigs fed DSM than in those fed any of the soybean protein sources; availability of these essential amino acids was higher from ISP and SPC than from the SBM diet. For the other essential amino acids, there were no significant differences among DSM, ISP and SPC diets.

The availability of overall essential amino acids measured over the entire digestive tract averaged 93.9, 92.8, 93.0 and 86.3% in pigs fed the DSM, ISP, SPC and SBM diets, respectively (Table 4.7). The fecal availabilities of nitrogen and essential amino acids were higher (P<.01) for pigs fed the DSM, ISP and SPC than in those fed the SBM diet. In addition, the fecal availability of lysine was higher (P<.05) in pigs fed the DSM diet than in those fed ISP or SPC diets and higher (P<.05) in pigs fed ISP or SPC than in those fed the SBM diet. Similarly, the fecal availability of valine was higher (P<.05) in pigs fed DSM than in those fed the ISP and SPC diets while availability in pigs fed the ISP diet was similar to that in pigs fed the SPC diet. Availabilities of arginine and histidine in pigs fed the ISP or SPC diets at both sites were higher than those of pigs fed the dried skim milk diet although differences were not significant. The literature is essentially devoid of fecal AA availability estimates for early weaned pigs, comparision must be made with estimates reported for older growing-finishing pigs. The fecal availability estimates reported in this study for pigs fed the SBM diet are slightly lower than those reported for SBM by Tanksley et al. (1982), Rudolph et al. (1983), Jorgensen et al. (1984) and Sauer et al. (1982). Estimates ranging from 89 to 92% have been reported for the average fecal availability of the essential amino acids in SBM from growing-finishing pigs. Our lower value for fecal availability of essential amino acids in SBM (85.3%) is not surprising because the digestive capacity of the neonatal pig is still developing (Lewis et al., 1957; Hartman et al., 1961; Efird et al., 1982) ; proteolytic enzyme inhibitors in

SBM probably have a greater effect in young than in older pigs. Poor availability is thought to result from an allergic reaction to antigenic material in soybean meal. Of the many antigenic constituents present in soybean endosperm, most are denatured or removed during industrial processing.

The difference between fecal and ileal AA availability determined by subtracting ileal availabilities from fecal availabilities is shown in table 4.8. Positive values indicate a net disappearance of AA from the hindgut. The availabilities of nitrogen and all amino acids were consistently higher when measured over the total digestive tract than at the end of the small intestine, indicating a loss of nitrogenous components in the cecum and colon. Poppe and Meiser (1977) found that the difference between the digestibility of nitrogen to the ileum and in the feces was only 1.8 digestibility units for pigs fed casein when the ileal fistula was positioned 1 to 1.5 cm from the ileal-cecal junction. The difference between the N digestibility to the ileum and in the feces in the present experiment was higher than that obtained by Poppe and Meiser (1977), which would indicate that the microflora of the cecum and large intestine had an effect on the determination of digestibility of nitrogen and suggest that the microflora in the hind gut of weaning pig are fully active. Higher availabilities over the total digestive tract than availabilities at the end of the small intestine have been reported for N and most AA in soybean meal (Holmes et al., 1974; Tanksley et al., 1981; Sauer et al., 1982). Losses of amino acids in the hind gut were greatest for proline, glycine, thereonine and alanine; these amino acids had the lowest availabilities at the end of the small intestine. Perhaps low availabilities for these amino acids at the end of the small intestine is a result of their high concentration in endogenous secretions or slow absorption of these amino acids. In this study, we found that degradation of amino acids was higher than synthesis of amino acids by microorganisms in the hind gut since availabilities of all amino acids over the total digestive tract were higher than those for the terminal ileum. Disappearance of dry matter, nitrogen and amino acids from the large intestine was highest in pigs fed the SBM diet as expected since Sauer et al. (1977) reported an inverse relationship between availability at the terminal ileum and degradation of amino acid in the large intestine.

For the indispensable AA, differences between ileal and fecal AA availabilities ranged from 3.9 (arginine) to 9.4 (valine) percentage units in SBM, 3.8 (arginine) to 6.8 (threonine) percentage units in SPC, 3.2 (arginine) to 7.3 (threonine) percentage units in ISP and from 2.6 (arginine) to 7.4 (threonine) percentage units in DSM (Table 4.8).

Protein and amino acids infused into the pigs'large intestine are well digested, but the N absorbed is not retained and almost completely excreted in the urine

(Zebrowska, 1973a; Just et al., 1981), suggesting that amino acids disappearing from the large intestine have minimal nutritional value for the pig. For this reason, amino acid availabilities for the soybean products measured at the end of the small intestine should more accurately measure differences in the amino acid absorption than availabilities over the total digestive tract.

In general, the availability of both N and AA in pigs fed the SBM diet was lower than for those fed other dietary protein sources. This may reflect the presence of proteolytic enzyme inhibitors, indigestible carbohydrate complexes (NDF) and /or antigenic constituents (glycinin or beta-conglycinin) present in soybean endosperm; these may account for the inferior growth and efficiency observed for early weaned pigs fed the SBM diet compared to those fed milk or processed soybean protein diets. Similar availabilities of amino acids among the dried skim milk, isolated soy protein and soy protein concentrate diets reflect removal of antinutritional factor(s) and antigenic material(s) present in soybeans during producion of isolated soy proteins or soy protein concentrates (Kilshaw and Sissons, 1979; Stobo et al., 1983; Walker rt al., 1986a; Lennon et al., 1971).

Li et al (1989) found that pigs fed a soybean meal diet showed decreased growth performance, lowered villus height and increased serum IgG titers against soybean protein compared to those fed a diet formulated with milk protein.

However, there were no effects on those criteria when pigs were fed a milk protein, soy protein concentrate, or isolated soy protein. They concluded that some antigenic activity may be eleminated with special processing techniques. Low level of trypsin inhibitor and removal or denaturation of antigenic materials within ISP and SPC may account for similar growth performance and availability of nutrients when compared to DSM.

A linear increase over time (P<.05) was observed in both ileal and fecal availability of N, of EAA and NEAA with the exception of glutamic acid (Table 4.9 and 4.10). Several studies have been reported in which an increase in nutrient availability has been observed with increasing age in young growing pigs (Hays et al., 1959; Combs et al., 1963; Wilson and Leibholz, 1981d; Leibholz, 1982).

These changes in availability due to protein sources and time should be considered when formulating diets for young pigs, especially, when SBM is used for formulating diets as a supplemental protein source to meet minimum requirements for lysine.

The present results indicate that more precise diet formulation may be achieved when availability of the amino acids in a feedstuff are considered. The fecal analysis method may overestimate the availabilities of the indispensable amino acids, including amino acid such as lysine, which often is limiting in swine diets using soybean proteins as protein source. The ileal analysis method should be the method of choice for determining amino acid digestibilities in feedstuffs for weaning pigs. Formulation of diets based upon available amino acids should result in a more valid comparision of soybean protein versus milk protein.

TABLE 4.1

COMPOSITION OF EXPERIMENTAL DIETS

	Diet[a]			
Ingredients	DSM	ISP	SPC	SBM
Corn starch	13.60	14.47	9.935	4.13
Cerelose	13.60	14.47	9.935	4.13
Solka floc	5.00	5.00	5.00	5.00
Lactose	-	32.01	32.01	32.01
Soybean oil	5.00	5.00	5.00	5.00
Dried skim milk	60.88	-	-	-
Isolated soy Protein[b]	-	24.35	-	-
Soy protein Concentrate[c]	-	-	33.49	-
Soybean meal, 50%	-	-	-	45.30
Calcium carbonate	.08	.65	.67	.73
Dicalcium phosphate	.24	2.45	2.36	2.10
Vitamin, TM premix[e]	.95	.95	.95	.95
Salt	.30	.30	.30	.30
Apralan[d]	.10	.10	.10	.10
Chromic oxide	.25	.25	.25	.25

[a]DSM: dried skim milk protein diet; ISP: isolated soy protein diet; SPC: soy protein concentrate diet; SBM: soybean meal diet.

[b]Isolated soy protein, soluble, pp-620, Protein Technologies International.

[c]Soy protein concentrate, promocalf, Central Soya, Fort Wagne, IN.

[d]Contained 75 g Apramycin per lb.

[e]Supplied 8,800 IU vitamin A, 880 IU vitamin D, 37 IU vitamin E, 44 mg pantothenic acid, 59 mg niacin, 8.8 mg riboflavin, 7.3 mg menadione sodium bisulfate, .04 mg vitamin B_{12}, 3 mg biotin, 6 mg pyridoxine, 2 mg folic acid, 10 mg thiamin, 880 mg choline chloride, .2 mg selenium, .06 g manganese, .2 g zinc, .2 g iron, .2 g copper, .2 g magnesium, 1.0 g potassium, and .4 mg iodine, per kg of feed.

TABLE 4.2

NUTRIENT COMPOSITION OF DIETS

Item	Diet (% DM basis)[a]			
	DSM	ISP	SPC	SBM
Calculated analysis (%)				
Crude protein	22.00	22.00	22.00	22.00
Calcium	.86	.86	.86	.86
Phosphorus	.67	.67	.67	.67
Lactose	31.05	31.05	31.05	31.05
Lysine	1.46	1.56	2.11	1.41
Tryptophan	.27	.34	.50	.31
Threonine	.97	.88	1.41	.86
Met + Cys	.79	.63	1.00	.64
ME (Kcal/kg)	3348.40	3263.92	3249.18	3371.72

[a]For explanation of diet code names, see Table 1.

TABLE 4.3

PROTEIN AND AMINO ACID COMPOSITION OF DIETARY PROTEIN SOURCES

Item	Diet[a]			
	DSM	ISP	SPC	SBM
Crude protein, %	35.77	89.55	68.07	50.03
Amino acids, g/16 g N				
Essential				
Arginine	3.11	7.43	7.05	7.04
Histidine	2.32	2.52	2.45	2.50
Isoleucine	4.30	4.30	4.07	4.02
Leucine	9.25	8.16	7.52	7.48
Lysine	5.97	6.15	6.64	6.07
Methionine	2.47	1.02	1.10	1.14
Phenylalanine	4.00	5.26	5.07	4.97
Threonine	4.13	3.98	4.23	3.76
Valine	6.19	4.40	4.26	4.24
Nonessential				
Alanine	3.76	4.27	4.13	4.16
Aspartic acid	7.87	11.38	10.93	10.98
Cystine	1.13	1.04	1.18	1.22
Glutamic acid	18.72	19.41	18.02	18.01
Glycine	2.77	4.14	4.03	4.08
Proline	9.34	5.33	5.02	4.94
Serine	5.12	5.36	5.04	5.12
Tyrosine	3.59	3.69	3.31	3.28

[a]For explanation of diet code names, see Table 1.

TABLE 4.4

PROTEIN AND AMINO ACID COMPOSITION OF DIETS[a]

	Diet[b]			
Item	DSM	ISP	SPC	SBM
Crude protein, %	23.30	23.75	23.87	24.04
Amino acids, %				
Essential				
Arginine	.71	1.56	1.64	1.68
Histidine	.51	.58	.61	.64
Isoleucine	1.32	1.06	1.10	1.13
Leucine	1.99	2.01	2.02	2.12
Lysine	1.33	1.49	1.56	1.60
Methionine	.54	.35	.37	.38
Phenylalanine	.97	1.19	1.23	1.22
Threonine	.97	1.03	1.09	1.15
Valine	1.39	1.18	1.14	1.17
Nonessential				
Alanine	.90	1.15	1.19	1.13
Aspartic acid	1.73	2.77	2.89	3.02
Cystine	.23	.29	.37	.33
Glutamic acid	5.01	4.55	4.52	4.76
Glycine	.69	.92	.97	1.02
Proline	2.76	1.27	1.27	1.32
Serine	1.21	1.26	1.29	1.36
Tyrosine	.84	.75	.76	.83

[a]Dry matter basis.
[b]For explanation of diet code names, see Table 1.

TABLE 4.5

APPARENT AVAILABILITIES OF DRY MATTER AND ASH AT THE END OF THE SMALL INTESTINE AND OVER THE TOTAL TRACT OF EARLY WEANED PIGS[a]

	Diet[b]				
Ingredients	DSM	ISP	SPC	SBM	SEM
Dry matter, %					
Terminal ileum	84.72[c]	83.57[c]	82.74[c]	71.80[d]	2.2
Total tract	90.24[c]	89.29[c]	88.72[c]	82.27[d]	1.5
Difference[e]	5.52[f]	5.72[f]	5.98[f]	10.47[f]	.5
Ash, %					
Terminal ileum	60.92	59.17	58.40	59.00	2.6
Total tract	63.99	62.83	61.73	63.12	2.3
Difference[e]	3.07[f]	3.66[f]	3.33[f]	4.12[f]	1.1

[a]Values are means of 4 observations.
[b]For explanation of diet code names, see Table 1.
[e]Differences obtained by subtraction of ileal availabilities from total tract availabilities. SBM in DM availability differs from others (P<.01).
[cd]Means in the same row with different superscripts differ (P<.01).
[f]Availabilities of DM and ash between total digestive tract and ileum differ (P<.05).

TABLE 4.6

APPARENT ILEAL AVAILABILITY OF NITROGEN AND AMINO ACIDS IN MILK AND SOYBEAN SOURCES IN EARLY WEANED PIGS[a]

	Diet[b]				
Item	DSM	ISP	SPC	SBM	SEM
Nitrogen[c], %	89.22	88.32	87.65	77.29	1.8
Amino acids, %					
Essential					
Arginine[c]	88.4	90.7	90.4	82.2	2.3
Histidine[c]	86.5	88.4	88.2	80.5	2.0
Isoleucine[c]	92.2	90.2	90.1	81.9	2.2
Leucine[c]	92.5	91.8	91.6	82.2	.9
Lysine[c]	91.7[d]	88.2[e]	88.3[e]	79.3	1.7
Phenylalanine[c]	88.6	87.8	87.9	77.4	1.2
Threonine[c]	85.3	84.9	85.3	74.9	1.7
Valine[c]	89.5[d]	85.7[e]	85.6[e]	75.3	1.6
AVG.	89.3[f]	88.5[f]	88.4[f]	79.2[g]	1.6
Nonessential					
Alanine[c]	89.7	88.9	89.1	79.9	1.7
Aspartic acid[c]	88.6	90.2	89.3	81.2	1.6
Glutamic acid[c]	93.4	92.2	92.4	82.2	2.0
Glycine[c]	84.9[d]	81.7[e]	81.9[e]	73.5	1.9
Proline[c]	85.8	85.4	84.9	77.8	1.6
Serine[c]	94.4	93.7	93.2	84.5	1.4
Tyrosine[c]	89.9	88.5	86.9	77.8	3.1
AVG.	89.5[f]	88.7[f]	88.2[f]	79.5[g]	1.7

[a]Values are means of four observations.
[b]For explanation of diet code names, see Table 1.
[c]SBM differs from other diets($P<.01$).
[de]Means in the same row with different superscripts differ ($P<.05$).
[fg]Means in the same row with different superscripts differ ($P<.01$).

TABLE 4.7

APPARENT FECAL AVAILABILITIES OF NITROGEN AND AMINO ACIDS IN MILK AND SOYBEAN SOURCES IN EARLY WEANED PIGS[a]

	Diet[b]				
Item	DSM	ISP	SPC	SBM	SEM
Nitrogen[c], %	94.37	93.38	92.94	85.15	1.5
Amino acids, %					
Essential					
Arginine[c]	91.4	93.8	93.9	86.1	2.5
Histidine[c]	91.5	93.1	93.3	85.9	1.9
Isoleucine[c]	96.7	94.4	94.1	89.4	2.4
Leucine[c]	96.8	95.7	95.8	89.5	1.9
Lysine[c]	95.4[d]	92.3[e]	92.5[e]	85.1	2.2
Phenylalanine[c]	92.4	91.8	91.9	86.1	2.0
Threonine[c]	92.7	91.0	92.1	83.2	1.8
Valine[c]	94.4[d]	90.2[e]	90.3[e]	84.7	1.7
AVG.	93.9[f]	92.8[f]	93.0[f]	86.3[g]	1.8
Nonessential					
Alanine[c]	94.5	93.8	94.3	88.2	1.9
Aspartic acid[c]	92.7	93.2	92.4	86.4	1.7
Glutamic acid[c]	97.4	96.8	96.4	86.8	1.6
Glycine[c]	90.2	89.9	89.8	82.2	1.5
Proline[c]	90.7	89.9	90.2	82.3	1.7
Serine[c]	95.4	94.7	94.9	88.9	1.6
Tyrosine[c]	94.2	92.7	92.3	82.4	1.9
AVG.	93.6[f]	93.0[f]	92.9[f]	85.3[g]	1.7

[a]Values are means of four observations.
[b]For explanation of diet code names, see Table 1.
[c]SBM differs from other diets (P<.01).
[de]Means in the same row with different superscripts differ (P<.05).
[fg]Meams in the same row with different superscripts differ (P<.01).

TABLE 4.8

DIFFERENCE BETWEEN APPARENT FECAL AVAILABILITY ESTIMATES AND THOSE DETERMINED AT THE END OF THE SMALL INTESTINE IN EARLY WEANED PIGS[a]

	Diet[b]			
Item	DSM	ISP	SPC	SBM
Dry matter, %	5.52	5.72	5.85	10.47
Nitrogen, %	5.15	4.53	5.29	7.86
Amino acids, %				
Essential				
Arginine	2.6	3.2	3.8	3.9
Histidine	5.0	4.7	5.1	5.4
Isoleucine	4.5	4.2	4.0	7.5
Leucine	4.3	3.9	4.2	7.3
Lysine	3.7	4.1	4.2	5.8
Phenylalanine	3.0	4.0	4.0	8.7
Threonine	7.4	7.3	6.8	8.3
Valine	4.9	4.5	4.4	9.4
AVG.	4.4	4.5	4.6	7.1
Nonessential				
Alanine	4.8	4.9	5.2	8.3
Aspartic acid	4.1	3.0	3.1	5.2
Glutamic acid	4.0	4.6	4.0	4.6
Glycine	5.3	8.2	7.9	8.7
Proline	4.9	4.5	5.3	4.5
Serine	1.0	1.0	1.7	4.4
Tyrosine	4.3	4.2	5.4	4.6
AVG.	4.1	4.3	4.7	5.8

[a]Differences obtained by subtraction of the apparent ileal availability estimate from the apparent fecal availability estimate.

[b]For explanation of diet code names, see Table 1.

TABLE 4.9

EFFECT OF TIME ON APPARENT ILEAL AMINO ACID AVAILABILITY IN EARLY WEANED PIGS[a]

	Week				
Item	1	2	3	4	SEM
Dry matter, %	78.9	78.2	83.3	82.6	1.3
Nitrogen[c], %	82.8	83.2	87.7	88.4	.8
Amino acids, %					
Essential					
Arginine[c]	84.2	84.7	90.4	88.7	1.4
Histidine[c]	83.7	83.5	89.2	88.4	1.7
Isoleucine[c]	87.2	81.9	89.7	91.3	1.6
Leucine[b]	87.4	89.4	90.9	92.0	2.1
Lysine[c]	83.1	84.2	88.3	90.7	2.0
Phenylalanine[c]	84.2	85.1	86.9	88.4	1.6
Threonine[c]	78.5	78.7	84.7	85.7	1.9
Valine[c]	83.6	83.4	85.8	88.4	1.9
AVG.	84.0	83.9	88.2	89.2	1.8
Nonessential					
Alanine[b]	85.3	85.9	88.3	91.3	1.8
Aspartic acid[c]	84.2	84.7	89.5	90.2	2.0
Glutamic acid	89.7	88.6	90.8	89.3	2.0
Glycine[b]	76.9	77.7	82.1	83.4	2.1
Proline[c]	80.2	80.4	83.3	84.9	1.8
Serine[c]	86.4	85.2	91.3	92.2	1.7
Tyrosine[c]	83.2	83.7	89.0	89.7	1.9
AVG.	83.7	83.7	87.8	88.7	2.0

[a]Values are means of four observations.
[b]Linear effect $P<.01$.
[c]Linear effect $P<.05$.

TABLE 4.10

EFFECT OF TIME ON APPARENT FECAL AMINO ACID AVAILABILITY IN EARLY WEANED PIGS[a]

	Week				
Item	1	2	3	4	SEM
Dry matter, %	85.6	84.8	90.4	89.2	.5
Nitrogen[c], %	89.1	89.7	93.1	94.3	1.1
Amino acids, %					
Essential					
Arginine[c]	87.1	89.6	91.2	93.4	1.6
Histidine[c]	86.7	87.4	91.4	93.5	1.7
Isoleucine[c]	90.3	89.3	94.5	95.7	1.9
Leucine[c]	90.5	90.7	93.8	96.9	2.0
Lysine[b]	86.2	86.4	91.3	95.4	2.4
Phenylalanine[c]	87.2	86.9	90.6	92.6	2.2
Threonine[b]	81.2	83.2	89.6	91.7	1.9
Valine[c]	86.4	84.9	92.3	94.7	1.8
AVG.	87.0	87.3	91.8	94.2	1.9
Nonessential					
Alanine[c]	87.4	87.9	91.6	94.2	1.9
Aspartic acid[c]	86.5	89.2	90.8	93.9	2.0
Glutamic acid[c]	90.4	91.2	94.6	96.2	1.8
Glycine[b]	81.4	82.4	87.3	89.4	1.7
Proline[b]	83.2	84.5	87.4	90.7	1.5
Serine[c]	91.2	92.6	93.4	95.4	1.8
Tyrosine[b]	86.9	87.0	91.7	94.9	1.9
AVG.	86.7	87.8	91.0	93.5	1.8

[a]Values are means of four observations.
[b]Linear effect $P<.01$.
[c]Linear effect $P<.05$.

LITERATURE CITED

Allee, G. L and P. H. Hsu. 1981. Performance and digestibility of milk replacers containing different sources and levels of soybean protein. J. Anim. Sci. 53(Suppl. 1):233(Abstr.).

Agricultural Research Council. 1981. The nutrient Requirements of pigs. Commonwealth Agricultural Bureau, Farnhan Royal.

AOAC. 1980. Official Methods of Analysis (13th Ed.). Association Of official Analytical Chemists, Washington, DC.

Austic, R. E. 1983. The availability of amino acids as an attribute of feeds. In: Robards, G. E and R. G. Packham (Editors), Feed information and animal production. Commonwealth Agricultural Bureaux, Slough, PP. 175-189.

Bacigalupo, F. A., J. R. Couch and P. B. Pearson. 1950. Effect of sucrose, lactose, galactose and fructose on fecal excretion of biotin, riboflavin and PGA in the mature cotton rat. Am. J. Physiol. 162:131.

Bayley, H. S and W. E. 1970. Comparision of simple and complex diets for baby pigs: Effect of form of feed and of glucose addition. J. Anim. Sci. 30:394.

Bayley, H. S and J. H. G. Holmes. 1972. Protein source for early weaned pigs. J. Anim. Sci. 35:1101(Abstr.).

Bayley, H. S., C. Y. Cho and J. H. G. Holmes. 1974. Examination of amino acids in ileal digesta as a measure of protein digestion. Fed. Proc. 33:94.

Bowman, D. E. 1944. Fractions derived from soya beans and navy beans which retard tryptic digestion of casein. Proc. Soci. Exp. Biol. Med. 57:139.

Braud, R., K. G. Mitchell, M. J. Newport and J. W. G. Porter 1970. Artificial rearing of pigs. 1. Effect of frequency and level of feeding on performance and digestion of milk proteins. Brit. J. Nutr. 24:501.

Bressani, R., F. Viteri, L. G. Elias, S. dezaghi, J. Alvarado and A. D. Odell. 1967. Protein quality of a soybean protein textured food in experimental animal and children. J. Nutr. 93:349.

Buraczewski, S., J. W. G. Porter, B. A. Rolls and T. Zebrowska. 1971. The course of digestion of different food proteins in the rat. 2. The effect of feeding carbohydrate with proteins. Brit. J. Nutr. 25:299.

Campbell, R. G. 1976. A note on the use of feed flavor to stimulate the feed intake of weaned pigs. Anim. Production. 23:417.

Carpenter, K. J., J. Duckworth, G. M. Ellinger and D. H. Shrimpton. 1952. The nutritional evaluation of protein concentrate obtained from the alkali digestion of herrings. J. Sci. Food Agr. 3:278.

Cera, K. R., D. C. Mahan, R. F. Cross, G. A. Reinhart and R. E. Whitmoyer. 1988. Effect of age, weaning and post-weaning diet on small intestinal growth and jejunal morphology in young swine. J. Anim. Sci. 66:574.

Circle, S. J and A. K. Smith. 1972. In Soybeans: Chemistry and technology, Vol. 1. Proteins, P. 294 [A. K. Smith and S. J. Circle, editors]. Connecticut: The Avi Pub. Company Inc.

Circle, S. J and D. W. Johnson. 1958. Edible isolated protein. In Processed plant protein foodstuffs, ed., A. M. Altschul. Academic press, New York, P 403.

Coalson, J. A., E. E. Jones and J. G. Leece. 1972. Diets using soy flour for pigs 3 weeks of age. J. Anim. Sci. 35:214(Abstr.).

Coalson, J. A and J. G. Leece. 1973. Herd differences in the expression of fetal diarrhea in artificially reared piglets weaned after 12 hr. vs 36 hr of nursing. J. Anim. Sci. 36:1114.

Colvin, B. M and H. A. Ramsey. 1968. Soy flour in milk replacer for young calves. J. Dairy Sci. 51:898.

Combs, G. E., F. L. Osegueda, H. D. Wallace and C. B. Ammerman. 1963. Digestibility of rations containing different sources of supplementary protein by young pigs. J. Anim. Sci. 22:396.

Combs, G. E., W. L. Alsmeyer, H. D. Wallace and M. Koger. 1960. Enzyme supplementation of baby pig rations containing different sources of carbohydrate and protein. J. Anim. Sci. 19:932.

Corring. T and R. Saucier. 1972. Secretion pancreatique sur porc fistule adaptation a la teneur en proteines du regime. Ann. Biol. Anim. Biochem. Biophys. 12(2):233.

Cranwell. P. D and D. A. Titchen. 1976. Gastric secretion in the young pigs. Proc. Nutr. Sco. 35(1):28A.

Craven, J. A and D. A. Barnum. 1971. Distribution of porcine fecal coliflora throughout a barn. Can. J. Com. Med. 35:274.

Cunningham, H. M. 1959. Digestion of starch and some of its degradation products by newborn pigs. J. Anim. Sci. 18:274.

Cunningham, H. M and G. J. Brisson. 1957. The effect of proteolytic enzymes on the utilization of animal and plant proteins by newborn pigs and the response to predigested protein. J. Anim. Sci. 16:568.

Ducuypere, J. A., A. Meeusen and H. K. Henderickx. 1981. Influence of the partial replacement of milk protein by soybean protein isolates with different physical properties on the performance and nitrogen digestibility of early weaned pigs. J. Anim. Sci. 53:1011.

Ducuypere, J. A., K. H. Hendericks and R. Bossuyt. 1978. Gastric secretion in suckling pigs and early weaned pigs given a dry cow's mild formula ad libitum. Br. J. Nutr. 40(1):91.

De Groot, A. P and P. Slump. 1969. Effects of severe alkali treatment of proteins on amino acid composition and nutritive values. J. Nutr. 98:45.

Diaz, G. R., M. A. Devaux, C. D. Johnson, Z. Adrich and H. Sarles. 1982. Physiological conditions for the study of basal and meal stimulated exocrine pancreatic secretion in the dog. Absence of feedback inhibition of basal secretion. Can. J. Physiol. Pharmacol. 60:1287.

Dietz, G. N., C. V. Maxwell and D. S. Buchanan. 1988. Effect of protein source on performance of early weaned pigs. J. Anim. Sci. 66(suppl.1):314(Abstr.).

Duke, W. W. 1934. Soybean as a possible important source of allergy. J. Allergy. 5:300.

Dunsford, B. R., D. A. Knabe and E. E. Haensly. 1989a. Effect of dietary soybean meal on the microscopic anatomy of the small intestine in the early weaned pig. J. Anim. Sci. 67:1855.

Dunsford, B. R., W. E. Haensy and D. A. Knabe. 1989b. Small intestinal goblet cell concentrations decrease in early weaned pigs fed different forms of soy protein. J. Anim. Sci. 67(Suppl. 1):262(Abstr.).

Eastham, E. J., T. Lichanco, M. I. Grady and W. A. Walker. 1978. Antigenicity of infant formulas: Role of immature intestine on protein permeability. J. Pediatrics. 93(4):1011.

Efird, R. C., W. D. Armstrong and D. L. Herman. 1982. The development of digestive capacity in young pigs: Effects of age and weaning system. J. Anim. sci.55:1380.

Eggum, B. O. 1970. Blood urea measurement as a technique for assessing protein quality. Brit. J. Nutr. 24:983.

Forbes, R. M and J. W. Erdman,Jr. 1983. Bioavailability of trace mineral elements. Annual Review of Nutrition. 3:213.

Freeman, H. J. 1984. Amino acid and dipeptide absorption in rats fed chemically defined diets of differing fiber composition. Can. J. Physiol. Pharmacol. 62:1097.

French, R. B and G. R. Cowgil. 1937. Immaturity of the organism as a factor determining the favorable influence of lactose on utilization of calcium and phosphorus. J. Nutr. 14:383.

Gargallo, J and D. Zimmerman. 1981. Effect of casein and starch infusion in the large intestine on nitrogen metabolism of growing swine. J. Nutr. 111:1390.

Gestetner, B., Y. Birk and Y. Tencer. 1968. Soybean saponins Fate of ingested soybean saponins and the physiological aspect of their hemolytic activity. J. Agrical and Food Chemistry. 16:1031.

Geurin. H. B., G. A. Kesel, W. T. Black, T. B. Hatfield and C. N. Daniels. 1988. Effect of isolated soy protein and whey on replacing dried skim milk in a prestarter for weaned baby pigs. J. Anim. Sci. 66(Suppl. 1):320 (Abstr.).

Giesting, D. W., K. W. Kelly and R. A. Easter. 1987. Evaluation of early exporsure to soy protein on pre- and postweaning performance and immunological characteristics of young pigs. J. Anim. Sci. 63(Suppl. 1):278(Abstr.).

Giesting, D. W., R. A. Easter and B. A. Roe. 1985. A comparision of protein and carbohydrate sources of milk and plant origin for starter pigs. J. Anim. Sci. 61(Suppl. 1):299(Abstr.).

Gitler, C. 1964. In mammalian protein metabolism. Vol.1. P 35. [J. B. Allison, editor]. London and New york: Academic press.

Glaser. J and D. E. Johnstone. 1953. Prophylaxis of allergic disease in the newborn. J. Am. Med. Assoc. 153:620.

Gorrill, A. D. L and J. W. Thomas. 1967. Body weight changes, pancreas size and enzyme activity and proteolytic enzyme activity and protein digestion in intestinal contents from calves fed soybean and milk protein diets. J. Nutr. 92:215.

Grant, A. L., J. W. Thomas, R. S. Emery, K. J. King and J. S Liesman. 1987. Small intestinal(SI) parameters in piglets fed an all-milk protein milk replacer or a special soy protein concentrate replacer supplemented with amines. J. Anim. Sci. 65(Suppl. 1):293(Abstr.).

Green, B. M and R. L. Lyman. 1972. Feedback regulation of pancreatic enzyme secretion as a mechanism for trypsin inhibitor-induced hypersecretion in rats. Proc. Soc. Exp. Biol. Med. 140:6.

Halpern, S. R., W. A. Sellars, R. B. Johnson, D. W. Anderson S. Saperstein and J. S. Reisch. 1973. Development of childhood allergy in infants fed breast, soy or cow milk. J. Allergy Clin.Immunol. 51:139.

Ham, W. E and R. M. Sandstedt. 1944. A proteolytic inhibiting substance in the extract from unheated soybean meal. J. Biol. Chem. 154:505.

Hamilton, D. L and W. E. Roe. 1977. Electrolyte levels and net fluid and electrolyte movements in the gastro-intestinal tract of weaning swine. Can. J. Comp. Med. 41(3):241.

Hampson, D. J. 1986a. Alterations in piglet small intestinal structure at weaning. Res. Vet. Sci. 40:32.

Hampson, D. J. 1986b. Attempts to modify changes in the piglet small intestine after weaning. Res. Vet. Sci. 40:313.

Hampson, D. J and D. E. Kidder. 1986. Influence of creep feeding and weaning on brush border enzyme activities in the piglet small intestine. Res. Vet. Sci. 40:24.

Hancock, J. D., E. R. Peo, Jr., A. J. Lewis and R. A. Moxley

1988. Effect of ethanol extraction and duration of heat treatment of soy flakes on function and morphology of pig intestine. J. Anim. Sci. 66(Suppl. 1);320(Abstr.).

Hanlon, M. H and I. E. Liener. 1986. A kinetic analysis of the inhibition of rat and bovine trypsins by naturally occuring proteas inhibitors. Comp. Biochem and Physiol. 84B:53.

Hartman, P. A., V. W. Hays, R. O. Baker, L. H. Neagle and D. V. Catron. 1961. Digestive enzyme development in the young pig. J. Anim. Sci. 20:114.

Hays, V. W., V. C. Speer, P. A. Hartman and D. V. Carton. 1959. The effect of age and supplemental amino acids on the utilization of milk and soya protein by the young pig. J. Nutr. 69:179.

Henry, Y., P. H. Duee and A. Relat. 1976. Isoleucine requirement of the growing pig and Leucine-isoleucine interelationship. J. Anim. Sci. 42:357.

Heppell, L. M., J. W. Sissons and H. E. Pedersen. 1987. A comparision of the antigenicity of soya-bean based infant formulas. Br. J. Nutr. 58:393.

Herbst, J. J and O. Koldovsky. 1972. Cell migration and cortison induction of sucrase activity in jejunum and ileum. Biochem. J. 126:471.

Hill, L. W. 1942. The production of non-etiological skin hypersensitivity to foods by natural means in atopic persons. J. Allergy. 13:366.

Hodgdon, E. S., F. D. Horney and H. S. Bayley. 1977. Nitrogen metabolism in pigs receiving soybean and rapseed meal. Can. J. Anim. Sci. 57:832(Abstr.).

Holmes, J. H. G., H. S. Bayley, P. A. Leadbeater and F.D. Horney. 1974. digestion of protein in small and large intestine of the pig. Brit. J. Nutr. 32:479.

Hoppe, M. K., G. W. Libal, C. R. Hamilton and D. H. Zeman. 1989. Effect of postweaning diet on early weaned pig intestinal morphology and function. J. Anim. Sci. 67(Suppl. 1):238(Abstr.).

Horowitz, M. I. 1967. In handbook of physiology section 6, Alimentary Canal.[C. F. Code, editor]. Washigton, DC: American physiology society.

Ivan, M and D. J. Farrell. 1976. Nutritional evaluation of wheat. 5. Disappearance of components in digesta of pigs prepared with two re-entrant cannula. Anim.

Production. 23:111.

Johnson, I. T., J. M. Gee, K. Price, C. Curl and G. R. Fenwick. 1986. Influence of saponins on gut permeability and active nutrient transport in vivo. J. Nutrition. 116:2270.

Jones, E. E., J. A. Coalson and J. G. Lecce. 1977. Soy flour as a source of protein for baby pigs. J. Anim. Sci. 45:1073.

Jorgensen, H., W. C. Sauer and P. A. Thacker. 1984. Amino acid availabilities in soybean meal, sunflower meal, fish meal and meat and bone meal fed to growing pigs. J. Anim. Sci. 58:926.

Just, A., H. Jorgensen and J. A. Fernandez. 1981. The digestive capacity of the cecum-colon and the value of nitrogen absorbed from the hindgut for protein synthesis in pigs. Br. J. Nutr. 32:429.

Kellogg, T. F., V. W. Hays, D. V. Carton, L. Y. Quinn and V. C. Speer. 1964. Effect of level and source of dietary protein on performance and fecal flora of pigs. J. Anim Sci. 23:1089.

Kenworthy, R. 1976. Observations on the effects of weaning in the young pig. Clinical and histopathological studies of intestinal function and morphology. Res. Vet Sci. 21:69.

Kenworthy, R and D. W. Allen. 1966. Influence of diet and bacteria on small intestine morphology with special reference to early weaning and Escherichia coli: studies with germ free and gnatobiotic pigs. J. Comp Pathol. 76:291.

Kenworthy, R and W. E. Crabb. 1963. The intestinal flora of young pigs with reference to early weaning. Escherichia Coli and scours. J. Com. Pathology. 73:215.

Kilshaw, P. J and H. Slade. 1982. Villus atrophy and crypt elongation in the small intestine of preruminant calves fed with heated soybean flour or wheat gluten. Res. Vet Sci. 33:305.

Kilshaw, P. J and J. W. Sissons. 1979. Gastrointestinal allergy to soybean protein in preruminant calves. II. Antibody production and digestive disturbances in calves fed heated soybean flour. Res. Vet. Sci. 27:361.

Kjellman, N. I. M and S. G. O. Johansson. 1979. Soy versus cow's milk with a biparental history of atopic disease: development of atopic disease and immunologlobulins from birth to 4 year of age. Clinical allergy. 9:347.

Knudsen, K. B., E. M. Bradley, F. R. Lecocq, H. M. Bellamys and J. D. Welsh. 1968. Effect of fasting and refeeding on the histology and disaccharidase activity of the human intestine. Gastroenterology. 55:46.

Kornegay, E. T., H. R. Thomas and C. Y. Kramer. 1974. Evaluation of protein levels and milk products for starter diets. J. Anim. Sci. 39:527.

Krogdahl, A and H. Holm. 1983. Pancreatic proteinases from man, trout, rat, pig, cow, chicken, mink and fox. Enzyme activities and inhibition by soybean and lima bean proteinase inhibitors. Comp. Biochem and Phisiol. 74B: 403.

Kunitz, M. 1945. Crystallization of a trypsin inhibitor from soybean. Science. 101:668.

Lawrence, T. L. 1972. The effect of certain dietary factors in vivo pH changes and pepsin activity in the stomach of the growing pig. Br. Vet. J. 128:402.

Lebenthal, E., P. Sunshine and N. Kretchmer. 1973. Effect of prolonged nursing on the activity of intestinal lactase in rats. Gastroenterology. 64:1136.

Lebenthal, E., T. S. Choi and P. C. Lee. 1981. The development of pancreatic function in premature infants after milk based and soy-based formulas. Pedatr. Res. 15:1240.

Lecce, J. G., W. D. Armstrong, P. C. Crawford and G. A. Ducharme. 1979. Nutrition and management of early weanedpiglets: Liquid vs dry feeding. J. Anim. Sci. 48:1007.

Leece, J. G., R. K. Balsbaugh, D. A. Clare and M. W. King. 1982. Rotavirus and hemolytic enteropathogenic Escherichia weaning diarrhea of pigs. J. Clin. Microbiol. 16:715.

Leibbrant, V. D, V. W. Hays, R. E. Ewans and V. C. Speer. 1975. Effect of fat on performance of baby and growing pigs. J. Anim. Sci. 40:1081.

Leibholz, J. 1982. Utilization of casein, fishmeal and soybean proteins in dry diets for pigs between 7 and 28 days of age. Anim. Prod. 34:9.

Lengeman, F. W. 1959. The site of action of lactose in the enhancement of calcium utilization. J. Nutr. 69:23.

Lennon, A. M., H. A. Ramsey, W. C. Alsmeyer, A. J. Clawson and E. R. Barrick. 1971. Soy flour as a protein source for early-weaned pigs. J. Anim. Sci. 33:514.

Leterme, P., Y. Beckers and A. Thewis. 1989. Inter- and intravarietal variability of the trypsin inhibitor content of peas and his influence on apparent digestibility of crude protein by growing pigs. In: J. Huisman et.al.,(Ed.): Recent advances of research in antinutritional factors in legume seeds. Pudoc. Wageningen. 1989. P 121-124.

Lewis, C. J., D. V. Catron, C. H. Liu, V. C. Speer and G. C Ashton. 1955. Enzyme supplementation of baby pig diets. J. Agri. Food. Chem. 3:1047.

Lewis, C. J., P. A. Hartman, C. H. Lie, R. O. Baker and D. V Catron. 1957. Digestive enzymes of the baby pig. pepsin and trypsin. J. Agr. Food. Chem. 5:687.

Li, D. F., J. L. Nelssen, P. G. Reddy, F. Blecha, R. D. Klemm, J. D. Hancock and R. D. Goodband. 1989. Using immunological criteria to predict utilization of soybean proteins by the early weaned pigs. Page 48-53, Kansas State University, Swine Day, 1989.

Liener, I. E and M. L. Kakade. 1980. Protease inhibitors. In: I. E. Liener(Ed.): Toxic constituents of plant foodstuffs. Academic Press, New York. P 7-71.

Low, A. G. 1979. Studies on digestion and absorption in the intestines of growing pigs. 6. Measurements of the flow of amino acids. Br. J. Nutr. 41:147.

Low, A. G. 1980. Nutrient absorption in pigs. J. Sci. Food Agric. 31:1087.

Maner, J. H., W. G. Pond, J. K. Loosli. 1961. Utilization of soybean protein by baby pigs and by rats. J. Anim. Sci. 20:614.

Maner, J. H., W. G. Pond, J. K. Loosli and R. S. Lowrey. 1962. Effect of isolated soybean protein and casein on the gastric pH and rate of passage of food residues in baby pigs. J. Anim. Sci. 21:49.

Mason, V. C. 1984. Metabolism of nitrogenous compounds in the large gut. Proc. Nutr. Soc. 43:45.

Mason, V. C., A. Just and S. Bech-Anderson. 1976. Bacterial activity in the hindgut of pigs. 2. Its influence on the apparent digestibility of nitrogen and amino acids. Z. Tierphysiol. Tierernahr. Futtermittelkd. 36:310-324.

Mateo, J. P and T. L. Veum. 1980. Utilization of casein or isolated soybean protein supplemented with amino acids and glucose or lactose by neonatal piglets reared artificially. J. Anim. Sci. 50:689.

May, C. D., S. J. Fomon and J. Remigio. 1982. Immunologic consequences of feeding infants with cow milk and soy products. Acta. Pediatr. Scand. 71:43.

Miller, B. G., P. S. James, M. W. Smith and F. J. Bourne. 1986. Effect of weaning on the capacity of pig intestinal villi to digesta and absorb nutrients. J. Agric. Sci. 107:579.

Miller, B. G., T. J. Newby, C. R. Strokes and F. J. Bourne. 1984a. Influence of diet on postweaning malabsorption diarrhea in the pig. Res. in Vet Sci. 36:187.

Miller, B. G., T. J. Newby, C. R. Stokes and F. J. Bourne. 1984b. Creep feeding and post weaning diarrhea in piglets. Vet. Rec. 4:296.

Misir, R and W. C. Sauer. 1982. Effect of starch infusion at the terminal ileum on nitrogen balance and apparent digestibilities of nitrogen and amino acids in pigs fed meat and bone meal and soybean meal diets. J. Anim. Sci 55:599.

Moore, R. J., E. T. Kornegay, R. I. Grayson and M. D. Lindemann. 1988. Growth, nutrient utilization and intestinal morphology of pigs fed high-fiber diets. J. Anim. Sci. 66:1570.

Nakamura, Y., K. Yasumoto and H. Mitsudo. 1972. Effect of excess L-histidine diet on active transport of L-histidine by isolated rat small intestine. J. Nutr. 102:359.

Newby, T.J., B. Miller, C. R. Stokes, D. Hampson and F. J Bourne. 1984. Local hypersensitivity response to dietary antigens in earley weaned pigs. In: W. Haresign and D.J.A. Cole (Eds.) Recent Advances in Animal Nutrition. 1984. pp 49-59. Butterworths. London.

Newport, M. J. 1979. Artificial rearing of pigs. 9. Effect of replacement of dried skim milk by fish-protein concentrate on performance and digestion of protein. Br. J. Nutr. 41:103.

Newport, M. J and H. D. Keal. 1982. Artificial rearing of pigs. 12. Effect of replacement of dried skim milk by either a soy-protein isolate or concentrate on the performance of the pigs and digestion of protein. Br. J. Nutr. 48:89.

Niiyama, M., E. Deguchi., K. Kagota and S. Namioka. 1979. Appearance of N-labeled intestinal microbial amino acids in the venous blood of the pig colon. Am. J. Vet Res. 40:716.

Nitsan, Z and I. E. Liener. 1976. Enzymatic activities in the pancreas, digestive tract and feces of rats fed raw or heated soy flour. J. Nutrition. 106:300.

Nitsan, Z., R. Volcani, A. Hasdai and S. Gordin. 1972. Soybean protein substitute for milk protein in milk replacer for suckling calves. J. Dairy Sci. 55:811.

Nitsan, Z., R. Volcani, S. Gordin and A. Hasdai. 1971. Growth and nutrient utilization by calves fed milk replacers containing milk or soybean protein concentrate heated to various degrees. J. Dairy. Sci. 54:1294.

NRC. 1988. Nutrient requirements of domestic animals, No.2. Nutrient requirements of swine. Ninth Revised Ed. National academy of sciences- National research council Washington, DC.

Okai, D. B., F. X. Aherne and R. J. Hardin. 1981. Effects of creep and starter composition on feed intake and performance of young pigs. Can. J. Anim. Sci. 56:373.

Ostermer, G. A., L. E. Hampson and R. J. Meade. 1973. Leucine-isoleucine interelationship in the young pig. J. Anim. Sci. 36:674.

Owsley, W. F., D. E. Orr. Jr and L. F. Tribble. 1986. Effects of nitrogen and energy source on nutrient digestibility in the young pig. J. Anim. Sci. 63:492.

Partridge, I. G. 1981. A comparision of defluorinated rock phophate and decalcium phosphate, in diets containing either skim milk powder or soya bean meal as the main protein supplement, for early weaned pigs. Anim. Prod. 32:76.

Patchornik, A and M. Sokolovsky. 1964. Chemical interactions between lysine and dehydroalanine in modified bovine pancreatic ribonuclease. J. Amer. Chem. Soc. 86:1860.

Pecas, J. C., V. W. Hays and A. M. Thompson. 1964. Exclusion of the exocrine pancreatic secretions: Effect on digestibility of soybean and milk protein by baby pigs at various ages. J. Nutr. 82:277.

Pettigrew, J. E., B. G. Harmon. S. E. Curtis, S. G.

Cornelius, H. W. Norton and A. H. Jensen. 1977. Milk proteins for artificially reared piglets. III. Efficacy of sodium caseinate and sweet dried whey. J. Anim. Sci. 45:261.

Pond, W. G., J. T. Snook. D. A. McNeil, W. Snyder and B. R. Stillings. 1971a. Pancreatic enzyme activities of pigs up to three weeks of age. J. Anim. Sci. 33:1270.

Pond, W. G., W. Snyder, E. F. Walker, B. R. Jr. Stillings and V. Sidwell. 1971b. Comparative utilization of casein, fish protein concentrate and isolated soybean protein in liquid diets for growth of baby pigs. J. Anim. Sci. 33:587.

Purser, D. B. 1976. In from plant to animal protein. Reviews in Rural Science. II. P 39.[T. M. Sutherland, J. R. Mcwilliams and R. A. Leng, Eds]. Armidale: University of New England Publishing Unit.

Pusztai. A. 1989. Biological effects of dietary lectins. In: J. Huisman et.al.,(Eds.): Recent advances of research in antinutritional factors in legume seeds. Pudoc Wageningen. 1989. P 17-29.

Rackis, T. J., J. E. McGhee and A. N. Booth. 1975. Biological threshold levels of soybean trypsin inhibitors by rat assay. Cereal Chemistry. 52:85.

Rascon, A., D. S. Seidl, W. G. Jaffe and A. Aizman. 1985. Inhibition of trypsins and chymotrypsins from different animal species: a comparative study. Comp. Biochem and Physiol. 84B:53.

Ratner, B and L. V. Crawford. 1955. Soybean: anaphylactogenic properties. Ann. Allergy. 13:289.

Reddy, N. R., S. K. Sathe and D. K. Salunkhe. 1982. Phytates in legumes and cereals. Advances in Food Research. 28:1

Rudolph, B. C., L. S. Boogs, D. A. Knabe, T. D. Tanksley and S. A. Anderson. 1983. Digestibility of nitrogen and amino acids in soybean products for pigs. J. Anim. Sci. 57:373.

SAS. 1984. SAS Users Guide. Statistical Analysis System Institute. Carry, NC.

Sauer, W. C., R. Cichon and R. Misir. 1982. Amino acid availability and protein quality of canola and rapeseed meal for pigs and rats. J. Anim. Sci. 54:292.

Sauer, W. C., S. C. Strothers and R. J. Parker. 1977. Apparent and true availability of amino acid in wheat and middling by-products for growing pigs. Can. J. Anim. Sci. 57:775.

Schmidt, M. K., M. P. Sherry and T. L. Veum. 1973. Amino acid sources for neonatal piglets. J. Anim. Sci. 37:290.(Abstr.).

Schneeman, B. O and D. Gallaher. 1986. Pancreatic response to dietary trypsin inhibitors: Variations among species Advances in experimental medicine and biology. 199:185.

Schneider, D. L and L. P. Sarrett. 1966. Use of the hysterectomy-obtained SPF pig for nutritional studies of the neonate. J. Nutr. 89:43.

Schneider, D. L and L. P. Sarrett. 1969. Growth of baby pigs fed infant soybean formulas. J. Nutr. 98:279.

Schulman. K. 1973. Effect of weaning on the pH changes of the contents of the piglet stomach and duodenum. Nord. Vet. Med. 25:220.

Schwartz, S. E., G. D. Levine and C. M. Starr. 1982. Effects of dietary fiber on intestinal ion fluxes in rats. Am. J. Clin. Nutr. 36:1102.

Screenivasamurthy, V. 1967. Detoxification of aflatoxin in peanut meal by H2O2. J. Asso. Offic. Agr. Chem. 50:350.

Seegraber, F. J and J. L. Morrill. 1986. Effects of protein source in calf milk replacers on morphology and absorptive ability of small intestine. J. Dairy sci. 69:460.

Sewell, R. F and C. V. Maxwell,Jr. 1966. Effects of various sources of carbohydrates in the diet of early-weaned pigs. J. Anim. Sci. 25:796.

Sewell, R. F and J. P. West. 1965. Some effects of lactose on protein utilization in the baby pig. J. Anim. Sci. 24:239.

Sewell, R. F., B. E. Sheffy, R. G. Eggert and J. K. Loosli. 1953. Studies on the protein requirement of suckling pigs. J. Anim. Sci. 12:579.

Sherry, M. P., M. K. Schmidt and T. L. Veum. 1978. Performance of neonatal piglets mechanically fed diets containing corn, soybean meal and milk protein. J. Anim. sci.46:1250.

Siddons, R. C. 1968. carbohydrase activities in the bovine digestive tract. Biochem. J. 108:839.

Sissons, J. W., R. H. Smith and D. Hewitt. 1979. The effect of giving feeds containing soybean meal extracted with ethanol on digestive processes in the preruminant calf. Br. J. Nutr. 42:477.

Smith H. W and J. E. T. Jones. 1963. Observations on the alimentary tract and its bacterial flora in healthy and diseased pigs. J. Path. Bact. 86:387.

Smith, R. H and J. W. Sissons. 1975. The effect of different feeds, including those containing soybean products, on the passage of digesta from the abomasum of the ruminant calf. Br. J. Nutr. 33:329.

Snyder, H. E and T. W. Kwon. 1988. Soybean utilization. Page 130-135.

Soy fibers; a new approach to vegetable protein acceptability. 1967. Nutr. Rev. 25:305.

Stobo, I. J. F and J. H. B. Roy. 1978. The use of non-milk proteins in milk substitutes for calves. World. Anim. Review. 25:18.

Stobo, I. J. F., P. Ganderton and H. Connors. 1983. Effect of antigen level on the suitability of soya flours and soya concentrate as alternatives to milk protein in milk substitutes for the neonatal calf. Anim. Prodction. 36:512.

Sullivan, J. P. 1943. Protein concentrates from grasses. Science. 98:363.

Svendsen et al., 1974. IgA immunoglobulin levels in porcine sera and mammary secretions. Res. Vet. Sci. 15:65.

Tanksley, T. D., Jr and D. Knabe. 1980. Availability of amino acids for swine. Proc. 1980. Arkansas Nutr. Conf., Dept. Anim. Sci. Univ. of Arkansas, Fayetteville.

Tanksley, T. D., Jr and D. A. Knabe. 1982. Researchers outline amino acid digestibilities of some high-protein feedstuffs and use in swine diet formulations. Feedstuffs. 54(53):16, 29.

Tanksley, T. D., Jr. D. A. Knabe, K. Purser, T. Zebrowska and J. R. Corley. 1981. Apparent digestibility of amino acid and nitrogen in three cotton seed meals and one soybean meal. J. Anim. Sci. 52:769.

Tasman-Jones, C., R. Owens and A. L. Jones. 1982. Semipurified dietary fiber and small-bowel morphology in rats. Dig. Dis. Sci. 27:519.

Taverner, M. R and D. J. Farrell. 1981. Availability to pigs of amino acids in cereal grains. 3. A comparision of ileal availability values with fecal, chemical and enzymatic estimates. Br. J. Nutr. 46:173.

Turlington, W. H., G. L. Allee and J. L. Nelssen. 1989. Effects of protein and carbohydrate sources on digestibility and digesta flow rate in weaned pigs fed a high fat, dry diet. From the Kansas Agricultural Experiment Station.

Veum, T. L., R. G. Zamora and M. P. Sherry. 1986. Utilization of soybean and milk proteins by neonatal pigs reared artificially. Swine in biomedical research. P 1113.

Vohra, P and F. H. Kratzer. 1967. The importance of the source of isolated soybean protein in nutrition. Poult. Sci. 46:1016.

Waggle, D. H and C. W. Kolar. 1979. Types of soy protein products. In: H. L. Wilke., D. T. Hopkins and D. H. Waggle. Eds. Soy protein and human nutrition. P 33.

Walker, W. R. 1984. Protein utilization and amino acid availability in early weaned pigs. Ph.D. dissertation. OK. State Univ. Stillwater, OK.

Walker, W. R., C. V. Maxwell, F. N. Owens and D. S. Buchanan 1986a. Milk versus soybean protein sources for pigs: I. Effects of performance and digestibility. J. Anim. Sci. 63:505.

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

Wapnir, R. A., R. L. Hawkins and F. Lifshitz. 1974. Absorption of amino acids in malnourished rats. J. Nutr. 104:843.

Wapnir. R. A., R. L. Hawkins and F. Lifsitz. 1972. Hyperaminoacidemia effects on intestinal transport of related amino acids. Am. J. Physiol. 223:788.

Williams, C. H., D. J. David and D. Iismaa. 1962. The determination of chromic oxide in feces samples by automic absorption spectrophotometry. J. Agri. Sci. 59:381.

Wilson, R. H and J. Leibholz. 1979. Protein, fat and carbohydrate in the diets of pigs between 7 and 28 days of age. Anim. Prod. 28:391.

Wilson, R. H and J. Leibholz. 1981a. Digestion in the pig between 7 and 35 d of age. I. The performance of pigs given milk and soya-bean proteins. Br. J. Nutr. 115:301.

Wilson, R. H and J. Leibholz. 1981b. Digestion in the pig betweeb 7 and 35 d of age. II. The digestion of dry matter and the pH of digesta in pigs given milk and soya-bean protein. Br. J. Nutr. 45:321.

Wilson, R. H and J. Leibholz. 1981c. digestion in the pig between 7 and 35 d of age. III. The digestion of nitrogen in pigs given milk and soya-bean proteins. Br. J. Nutr. 45:337.

Wilson, R. H and J. Leibholz. 1981d. Digestion in the pig between 7 and 35 d of age. IV. The digestion of amino acids in pigs given milk and soya-bean proteins. Br. J. Nutr. 45:347.

Woodward, C. J H and K. K. Caroll. 1985. Digestibilities of casein and soya-bean protein in relation to their effects on serum cholesterol of rabbits. Br. J. Nutr. 54:355.

Wu, M. C., C. C. Wung, C. C. Kuo and F. S. Chang. 1988a. Effect of dietary antigen on the performance of early weaned pigs. I. Influence of dietary protein sources on plasma D-xylose concentrations in pigs weaned at 18 days of age. Annu. Res Rept. 45. Anim. Ind. Res. Inst. TSC.

Wu, M. C., L. C. Wung, C. C. Kuo and F. S. Chang. 1988b. Effect of dietary antigen on the performance of early weaned pigs. II. Influence of dietary protein sources on D-xylose concentrations in plasma of pigs weaned at 28 days of age. Annu. Res. Rept. 55. Anim. Ind. Res. Inst. TSC.

Yen, J. T., A. H. Jensen and J. Simon. 1977. Effect of dietary raw soybean and soybean trypsin inhibitor on trypsin and chymotrypsin activities in the pancreas and in small intestinal juice of growing swine. J. Nutr. 107:156.

Zamora, R. G., M. K. Schmidt and T. L. Veum. 1975. Protein levels and sources for neonatal piglets. J. Anim. Sci. 41:331.

Zebrowska, T. 1973a. Digestion and absorption of nitrogenous compounds in the large intestine of pigs. Rocz. Nauk. Rolnic 95(B):85.

Zebrowska, T. 1973b. Influence of dietary protein source on the rate of digestion in the small intestine of pigs. Part I. Amount and composition of digesta. Rocz. Nauk. Rolnic. 95(B):115.

Zebrowska, T. 1973c. Influence of dietary protein source on the rate of digestion in the small intestine of pigs. Part II. The rate of protein digestion and amino acid absorption. Rocz. Nauk. Rolnic. 95(B):136.

Zebrowska, T. 1978a. Determination of available amino acids in feedstuffs for monogastrics. Feedstuffs. 50(53):15, 17.

Zebrowska, T., L. Buraczewska and S. Buraczewski. 1978b. The apparent digestibility of amino acids in the small intestine and in the whole digestive tract of pigs fed diets containing different sources of protein. Roczn. Nauk. Roln. Ser. 99:87.

Zoppi, G., G. Androtti, F. Pajno-Ferrara, D. M. Njail and D. Gaburra. 1972. Exocrine pancreas function in premature and full term neonates. Pediatr. Res. 6:880.

1

VITA

Kwang Sou Sohn

Candidate for the Degree of

Doctor of Philosophy

Thesis: EFFECT OF PROTEIN SOURCE ON PERFORMANCE AND AMINO ACID AVAILABILITY IN EARLY WEANED PIGS

Major Field: Animal Nutrition

Biographical:

Personal Data: Born in Uljin, Korea, February 27, 1957, the son of Mr. and Mrs. Sun Chool Sohn.

Education: Graduated from Hoopo High School, Uljin, Korea, in February, 1974; Received Bachelor of Science degree in Animal Science from Yeung Nam University, Kyung San, Korea, in February, 1978; Received the Master of Science degree in Animal Science from Seoul National University, Seoul, Korea, in February, 1983; Completed the Requirements for the doctor of Philosophy degree in Animal Nutrition at Oklahoma State University Stillwater, Oklahoma in May, 1990.

Professional Experience: Graduate Student, Seoul National University, Department of Animal Science 1978-1983; Graduate student, Oklahoma State University, Department of Animal Science, 1986-1990.

Professional Organizations: Member of Korean Journal of Animal Science.