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Protein and Amino Acids for Swine

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In the U.S., the most challenging task in formulating swine diets is to provide the protein and amino acids needed for maximum lean growth and reproductive performance at the least cost. To formulate diets effectively, one must know: 1. The amino acid requirements of the different classes of pigs, and 2. The composition of the various feedstuffs and their ability to supply specific amino acids. The "competitive edge" goes to the person who can mesh these together in diets and a feeding program to produce lean pork at the most economical cost.

The factsheet will consider both amino acid requirements and the ability of various feedstuffs to supply the amino acids, but first let's review some basic concepts of protein and amino acid nutrition.

Protein vs. Amino Acids

The use of percent of crude protein to indicate the ability of a *mixed feed with unknown ingredients* to meet the amino acids needs of a pig's diet is out-dated and of little value. The content of essential amino acids gives a much better indication of nutritional quality than percent crude protein. This is because feed proteins differ widely in percentage of specific amino acids that they contain.

Muscle protein (lean tissue) is composed of about 20 different amino acids. Ten of these must be supplied in the pig's diet; the other amino acids can be synthesized in the body rapidly enough for maximum growth if a source of dietary nitrogen and adequate energy are present. The 10 that must be supplied in the diet are called essential amino acids; the others are classified as nonessential. The 10 essential amino acids are: lysine, tryptophan, threonine, methionine, isoleucine, valine, leucine, histidine, arginine, and phenylalanine.

Actually, swine do not have a protein requirement *per se*, but rather they have a dietary requirement for:

1. Specific amounts of the essential amino acids, and
2. Nonspecific nitrogen to synthesize the non-essential amino acids.

Any diet formulated from natural feedstuffs that satisfies the first requirement will automatically satisfy the need for nonspecific nitrogen.

The fallacy of using percent crude protein of a mixed feed with unknown ingredients as an indicator of amino acid quality is shown in Figure 1. Figure 1 shows the ability of a 16% protein corn-soybean meal diet, a 16% protein corn-meat and bone meal diet and a 16% protein corn-peanut meal diet to meet the growing pig's (40 to 80 lb.) requirement for lysine, tryptophan and threonine (the three most limiting amino acids in U.S. diets). The solid portions of the bars in Figure 1 show the contribution of corn in meeting the requirements for lysine (27%), tryptophan (33%), and threonine (49%). The diagonally lined portions in Figure 1 show the contribution of soybean meal, meat and bone meal and peanut meal, respectively, toward meeting the lysine, tryptophan, and threonine needs of the growing pig. Only the corn-soybean meal diet meets the requirements for all three amino acids to support maximum growth. The corn-meat and bone meal diet is very deficient in tryptophan and barely adequate in lysine. The corn-peanut meal diet is inadequate in both lysine and tryptophan and barely adequate in threonine. This indicates clearly that the crude-protein content of a mixed feed is an unreliable indicator of amino acid quality of the feed *unless one knows the feedstuffs used in preparing the feed.* If a crude-protein content of 9% is used for corn and sorghum in formulating diets, the crude-protein content of a corn-soybean meal or sorghum-soybean meal diet is very meaningful and is a reliable indicator of their ability to meet the amino acid needs of a pig at a specific weight. However, when other high protein feedstuffs are used instead of soybean meal, the crude-protein value is less meaningful.

Other Concepts of Amino-Acid Nutrition

1. Protein synthesis is an "all or nothing" process. If any one of the essential amino acids needed to syn-

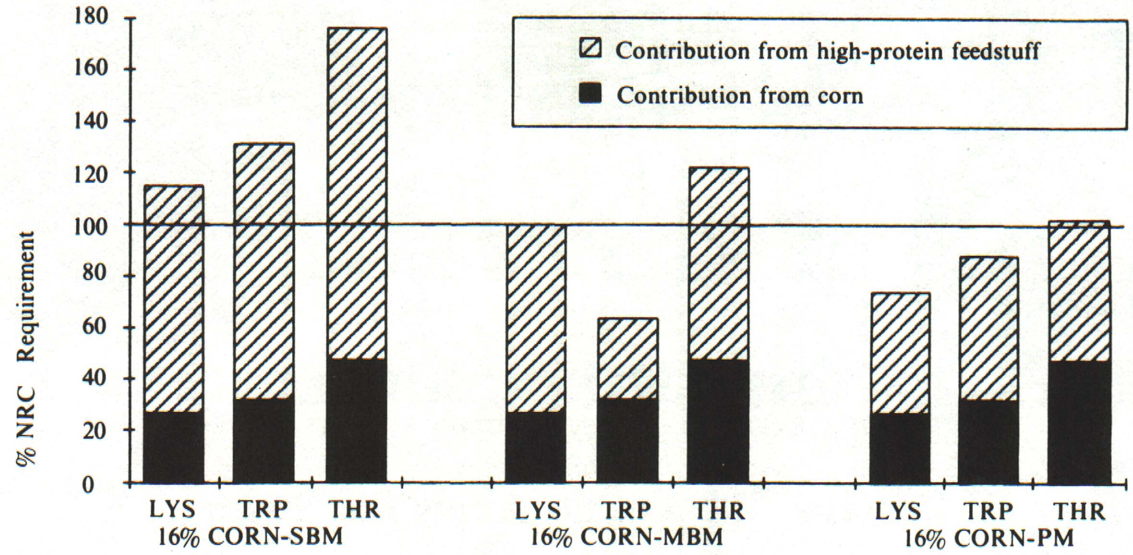

Figure 1. Ability of 16% crude protein corn-soybean meal, corn-meat and bone meal, and corn-peanut meal diets to meet the lysine, tryptophan, and threonine requirements of the growing pig.

thesize a body protein is deficient in the diet, that protein cannot be made. Nothing explains the concept of limiting amino acids better than the age-old illustration that likens a feed protein to a wooden barrel made up of rings and staves. The amino acids are the staves, and since a barrel will only hold water to the height of its lowest stave, a feed protein will only allow a pig to synthesize lean tissue to the level of the amino acid present in the least amount in relation to the pig's requirement. This amino acid, the shortest stave in the protein barrel, is called the first-limiting amino acid, the next in shortest supply, the second-limiting amino acid and so on. Therefore, quality of protein (presence and amount of the 10 essential amino acids), is more important than the amount of protein.

2. Amino acid requirements when expressed as a percentage of the diet, are truly a moving target because of the many factors that affect "the requirement." The most important include:
   A. Energy density of diet—amino acid requirements increase as energy level increases.
   B. Protein content of diet—requirement for a specific amino acid increases as dietary protein level increases.
   C. Genetic potential for muscle growth—higher for leaner, more muscular animals.
   D. Sex—higher for gilts than barrows, highest for boars.
   E. Criteria used in establishing requirements —requirements for feed efficiency and carcass leanness are higher than for weight gain.
   F. Interrelationships among amino acids—cystine can provide at least 50% of the requirement for total sulfur amino acids (methionine + cystine). Tyrosine can provide at least 50% of the requirement for total aromatic amino acids (phenylalanine + tyrosine).

3. Pigs utilize the L-isomers of all amino acids (L-isomers are present in natural feedstuffs—crystalline amino acids may be in L-form or a combination of L and D forms). Pigs also utilize the D-isomers of methionine and tryptophan effectively. D-methionine is equal to L- methionine; D-tryptophan has 60 to 70% of the biological value of L- tryptophan. The D-isomers of lysine and threonine are useless for pigs.

4. A diet with good amino acid balance, even though it is below the recommended level in total protein and essential amino acids, has little or no depressing effect on voluntary feed intake. However, a deficiency of even one essential amino acid or an imbalance of amino acids (excess of one or more in relation to others) usually causes a reduction in feed intake and growth rate.

These concepts provide guidelines that must be considered when attempting to make generalizations about the protein and amino acid needs of swine to optimize reproductive efficiency, feedlot performance, carcass merit, and production costs.

Amino-Acid Requirements

Requirements for the essential amino acids at different weights of growing-finishing pigs and for breeding swine are shown in Table 1. In all cases, the requirements refer to the amount of L-isomer required. These requirements are "averages" for published data that optimized performance. These are minimum requirements, they do not include a safety factor; therefore, it may be necessary to increase the level of certain amino acids under specific conditions. Most requirements have been determined using corn-soybean meal diets containing about 1425 kcal metabolizable energy/pound. Therefore, they may need modification if other feed ingredients are used, especially if there are appreciable differences in amino acid digestibility or in energy content. Amino acid requirements for growing-finishing pigs, expressed as a percent of the diet, decrease as a pig becomes heavier. Requirements are highest during the rapidly growing stages of the young

Table 1. Amino acid requirements of swine (percent of diet).[a]

	Growth Phase (Ad libitum-fed)					
	Early Wean	Starting	Growing	Finishing	Bred gilts & sows; young & adult boars[b]	Lactating gilts & sows[c]
Liveweight, lb.	11-22	22-44	44-110	110-230		
Expected daily gain, lb.	.55	1.00	1.60	1.80		
Expected feed intake, lb./day	1.00	2.10	4.20	6.85		
Expected feed/gain	1.82	2.10	2.65	3.80		
	Percent					
Crude protein[d]	20	18	16	13	12	13.5
Lysine	1.15	.95	.70	.60	.43	.60
Tryptophan	.17	.14	.12	.10	.09	.12
Threonine	.68	.56	.48	.40	.30	.43
Methionine + cystine[e]	.58	.48	.41	.34	.23	.36
Isoleucine	.63	.52	.45	.37	.30	.39
Valine	.68	.56	.48	.40	.32	.60
Leucine	.85	.70	.60	.50	.30	.48
Histidine	.31	.25	.22	.18	.15	.25[g]
Arginine	.50	.40	.25	.10	.00	.40[g]
Phenylalanine + tyrosine[f]	.94	.77	.66	.55	.45[g]	.70[g]

[a]Requirements are the estimated levels needed for optimal performance when a fortified corn-soybean meal diet is fed. Concentrations are based on air-dry diet (i.e., 90% dry matter).

[b]Bred gilts and sows should generally be fed 4 lb. feed/day; gilts should gain about 95-100 lb. and sows about 75 lb. during gestation; boars should be fed 3 to 6 lb./day depending on condition. Requirements for boars have not been determined, but are assumed to be similar to those established for bred gilts and sows.

[c]Lactation feed intake will be influenced by parity and size of litter nursed, but generally falls in the range of 8 to 12 lb for first-litter sows and 12 to 16 lb for mature sows.

[d]Approximate protein levels needed to provide essential amino acids when a fortified corn-soybean meal diet is fed (Cr. protein of corn 9.0%, soybean meal 44%). By adding supplemental L-lysine; protein requirements in starting and growing diets can be lowered by two percentage units (i.e., from 16 to 14%).

[e]Methionine can fulfill the total sulfur amino acid requirement; cystine can supply at least 50% of the total requirement.

[f]Phenylalanine can fulfill the total aromatic amino-acid requirement; tyrosine can supply at least 50% of the total requirement.

[g]These levels are adequate; the actual requirement has not been established.

animal. Not only does the young animal grow at a more rapid rate (greater percentage increase in body weight per day) but also the percentage of protein in weight gain is higher than during the finishing period. These changes in rate of growth and body composition have been the basis for recommending different dietary protein levels to meet the amino acid requirements during the life of the pig. From a practical standpoint, any combination of natural feedstuffs that supply adequate quantities of the "big three" amino acids (lysine, tryptophan, and threonine) will also provide adequate amounts of the other essential amino acids needed to optimize weight gain and feed efficiency of growing-finishing pigs.

Requirements for pregnant gilts and sows are based on the amounts required for satisfactory nitrogen retention during the later stages of pregnancy. Requirements are minimal during gestation because sows deposit only 0.25 lb. of protein per day in their fetuses. Studies have clearly demonstrated that sows have a remarkable capacity to buffer their developing fetuses against dietary protein or amino acid deficiencies. Feeding low levels of protein and amino acids during gestation appears to have little effect on farrowing performance but reduces lactation and rebreeding performance. The bottom line is that gestating sows need at least 8 to 9 g of lysine per day to optimize reproductive performance.

The requirements for lactation have been determined experimentally or have been extrapolated from published requirements for maintenance of adult sows plus amounts calculated to support good milk production. Grain-soybean meal diets containing 14% protein should provide adequate amounts of all essential amino acids for lactation. However, to optimize milk yield and rebreeding performance, adequate feed intake is mandatory. Older sows should consume 12 lb. or more of feed per day while first litter sows usually consume 2 to 4 lb. less per day. For convenience, many producers desire to use the same diet for both gestation and lactation. If this is done, a 14% protein grain-soybean meal diet is recommended.

Amino Acids in Grain

Although cereal grains are used primarily as sources of energy in swine feeding, they also contribute protein and amino acids. The essential amino acid composition of today's corn and sorghum hybrids are quite similar as shown in Table 2. Compared to the 40 lb. pig's requirement, lysine is the first-limiting amino acid in both grains, although experiments with corn have revealed that tryptophan is often as limiting as lysine. For the 40 lb. pig, both grains contain adequate amounts of arginine, histidine, leucine, and phenylalanine plus tyrosine. Both are deficient in lysine, tryptophan, threonine, total sulfur amino acids, and isoleucine.

Oats, wheat, and barley are higher in protein than is corn, but they contribute little more toward meeting the amino acid requirements of the growing pig because they are also deficient in lysine, threonine, isoleucine, and the sulfur-containing amino acids. However, all of these grains contain more lysine than corn and sorghum. Hence, slightly less high protein supplement is required in formulating diets containing these grains. The most efficient way to take advantage of the superior amino acid content of oats, wheat, and barley is to balance the diets on a lysine basis. A less precise, but acceptable, method is to figure these grains at 11% protein as compared to 9%

Table 2. Protein and essential amino acid content of commonly used swine feeds.[a]

	Protein	Lysine	Tryptophan	Threonine	Met + Cys[b]	Isoleucine	Valine	Leucine	Histidine	Arginine	Phe + Tyr[c]
	Percent										
Grains[d]											
Corn	8.8	.25	.05	.32	.38	.31	.46	.98	.24	.42	.76
Sorghum	9.0	.22	.09	.29	.31	.38	.70	1.13	.21	.36	.83
Barley	11.7	.36	.16	.36	.36	.54	.63	.81	.27	.58	.99
Oats	12.0	.34	.13	.31	.33	.39	.46	.66	.15	.58	.78
Wheat	12.2	.38	.15	.37	.36	.46	.55	.88	.28	.60	1.00
Corn, high lysine	9.5	.35	.07	.35	.32	.33	.47	.93	.33	.62	.78
Protein Sources[d]											
Soybean meal	44	2.88	.55	1.87	1.12	2.32	2.31	3.62	1.21	3.20	3.81
Soybean meal	48.5	3.18	.63	2.00	1.30	2.60	2.48	3.88	1.30	3.54	4.08
Alfalfa meal, dehydrated	17	.80	.36	.58	.58	.72	.80	1.09	.29	.94	1.15
Blood meal, spray or ring-dried	85	8.10	1.10	4.10	3.00	1.00	9.10	12.70	5.50	4.10	10.30
Canola meal, solvent	37	1.98	.43	1.56	1.01	1.35	1.79	2.50	.99	2.06	2.20
Corn gluten feed	22	.61	.06	.75	1.00	.84	1.05	2.10	.58	.75	1.46
Cottonseed meal, solvent	41	1.55	.48	1.19	.98	1.18	1.60	2.12	1.00	4.27	2.99
Distillers dr. solubles (corn)	27	.77	.18	1.01	.86	1.72	1.61	2.21	.70	1.03	2.33
Fish meal (Menhaden)	60	4.60	.52	2.67	2.50	2.99	3.42	4.79	1.55	4.06	4.79
Meat meal	55	3.00	.36	1.74	1.40	1.60	4.32	5.26	1.95	3.69	3.74
Meat & bone meal	50	2.60	.28	1.56	1.00	1.40	2.42	3.12	.90	3.59	2.65
Peanut meal, solvent	50	1.39	.38	1.13	.87	1.47	2.72	2.62	.94	5.23	3.89
Skim milk, dried	32	2.40	.44	1.60	1.30	2.20	2.17	3.15	.82	1.09	2.56
Sunflower meal	32	1.66	.44	1.40	2.26	.99	1.58	1.58	.54	.23	1.48
Wheat bran	15	.56	.29	.38	.38	.56	.66	.85	.29	.95	.85
Wheat midds, standard	16	.64	.18	.54	.32	.73	.73	1.10	.37	.83	1.00
Whey, dried whole	12	.80	.15	1.03	.32	.72	.56	1.00	.16	.27	.44
Yeast, brewers dried	45	3.02	.50	2.12	1.21	2.12	2.31	3.23	1.11	2.22	3.44

[a]All values on a 90% dry-matter basis.

[b]Effective total sulfur amino-acid value. If cystine content was higher than methionine, it was reduced to the methionine value since cystine can provide only 50% of the total sulfur amino-acid requirement.

[c]Effective total aromatic amino acid value. If tyrosine content was higher than phenylalanine, it was reduced to phenylalanine content since tyrosine can provide only 50% of the total aromatic amino-acid requirement.

[d]Values obtained from Untied States-Canadian Tables of Feed Composition, Third Revision (National Academy of Sciences, 1982), and from the authors' laboratories, all values adjusted to the indicated protein level.

for corn and sorghum when formulating diets on a percent protein basis. Even though sorghum generally contains slightly more protein than does corn, the same amount of high protein feedstuff must be fed with sorghum as with corn, because the amount of lysine is usually slightly lower in sorghum than in corn (Table 2). Because it is relatively high in crude fiber, oats should generally not comprise more than 25% of a growing-finishing diet.

Even though the protein contents are similar, opaque 2 (high lysine) corn contains more lysine and tryptophan than does regular hybrid corn. Decisions concerning when to use high lysine corn in swine diets should be made on the basis of economics, yield characteristics and lysine content of the particular varieties available. Studies have indicated that commercially available high lysine corn contains between 30 to 40% more lysine and tryptophan than regular corn.

Amino Acids in High-Protein Feedstuffs

Since lysine, tryptophan, and threonine are most deficient in corn and sorghum, high protein feedstuffs should be evaluated primarily on their ability to correct these deficiencies, particularly that of lysine. Table 3 gives the lysine, tryptophan, and threonine content of several high protein feeds. High-protein feedstuffs vary widely in percentage of protein (from 12% for dried whole whey to 85% for blood meal). Therefore, *the amino acid content expressed as a percent of protein* is a good yardstick to use when evaluating the ability of a protein source to correct the amino acid deficiencies of grain without providing a large excess of other essential amino acids in the diet. In formulating a 16% protein grower diet using corn or sorghum and a 38% protein supplement, the supplement must contain minimum amounts (as a percent of the protein) of the following amino acids: lysine, 6.25%; tryptophan, 0.66%; and threonine, 2.41%.

Values in Table 3 indicate that only blood meal, fish meal, dried skim milk, dried whole whey, and soybean meal satisfy all the amino acid requirements. However, soybean meal is the only protein source that results in optimal performance when combined with grain. The available tryptophan content of blood and fish meals may be their limiting factor, while the lactose content of dried whey and dried skim milk would limit their use, especially for pigs over 8 weeks of age. Moreover, the supply and price of blood meal, fish meal, and milk products prevent their routine use in swine feeds.

Table 3. Lysine, tryptophan, and threonine content of selected feedstuffs.[a]

	Protein %	Lysine, %		Tryptophan, %		Threonine,%	
		Feed[b]	Protein[c]	Feed[b]	Protein[c]	Feed[b]	Protein[c]
Blood meal (ring-dried)	85	8.10	9.53	1.10	1.29	4.10	4.82
Fish meal (Menhaden)	60	4.60	7.67	.52	.87	2.67	4.45
Skim milk, dried	32	2.40	7.50	.44	1.38	1.60	5.00
Whey, dried whole	12	.80	6.66	.15	1.25	1.03	8.58
Soybean meal, solvent	44	2.88	6.55	.55	1.25	1.87	4.25
Soybean meal, solvent	48.5	3.18	6.55	.63	1.30	2.00	4.12
Meat meal	55	3.00	5.45	.36	.65	1.74	3.16
Meat & bone meal	50	2.60	5.20	.28	.56	1.56	3.00
Cottonseed meal, solvent	41	1.55	3.79	.48	1.17	1.19	2.90
Peanut meal, solvent	50	1.39	2.79	.38	.76	1.13	2.26
Corn gluten feed	22	.61	2.77	.06	.27	.75	3.41
Feather meal, hydrolyzed	85	1.94	2.28	.41	.48	3.75	4.41

[a]90% dry matter basis.

[b]Chemically determined percentage in feedstuff.

[c]Expresses the percentage of the amino acid as a percentage of the protein content which indicates the ability of a feedstuff to complement the amino acid deficiencies of the grains used.

Meat meal and meat and bone meal are limiting in lysine and tryptophan. Meat products are usually high in ash and should not comprise more than 3 to 5% of the complete diet.

Several high protein feeds in Table 3 are very deficient in lysine. These include: cottonseed meal, peanut meal, feather meal, and corn gluten feed. Cottonseed and peanut meals can be used effectively to provide a portion of the protein supplement, but they must be fed in combination with other high protein feedstuffs that have a high lysine content to obtain maximum performance.

Consideration of Amino-Acid Digestibilities in Formulating Diets

For many years, nutritionists have known that not all of the amino acids in feedstuffs, as determined by chemical analyses, are biologically available to the pig. Several things can limit digestion and absorption from the intestinal tract. Thus, much work has been directed toward determining amino acid digestibilities. Most of the data obtained in the late 1960's and early 1970's represented digestibilities measured over the total digestive tract. These fecal values have been used extensively, particularly in European countries, in formulating diets. However, recent experiments have shown that most of the protein that disappears from the large intestine is not used effectively by the pig. Therefore, in the past decade, researchers have focused on determining digestibilities at the end of the small intestines (terminal ileum) before the digesta enters the large intestine.

A summary of the protein, lysine, tryptophan, and threonine ileal digestibilities in several grains and high protein feedstuffs determined by European, Canadian and U.S. research groups is given in Table 4. Although data are incomplete at present, some generalizations can be made.

Among the cereal grains, ileal digestibilities are highest for wheat, corn, and oat groats, followed by sorghum and barley. The differences in digestibilities among the grains are relatively small. This, plus the relatively low lysine, tryptophan, and threonine content of the grains suggests that the use of ileal digestibilities will not improve significantly the precision of practical diet formulation when these grains are used. On the other hand, ileal digestibilities of wheat midds and corn gluten feed are considerably lower than the grains. Wheat midds are also relatively rich in total lysine, tryptophan, and threonine compared to cereal grains; therefore, the use of ileal digestibility values for these products may improve the precision of diet formulation.

Differences in digestibilities among the high protein feedstuffs are much wider than among the grains. Furthermore, high protein feedstuffs are more important in diet formulation because they provide over 70% of the first-limiting amino acid (lysine) in a corn or sorghum-based grower diet. Some observations among high protein feedstuffs include:

1. Digestibilities of amino acids are excellent in soybean meal, dried skim milk blood meal,, fish meal, poultry by-product meal, and glandless cottonseed meal.

2. Regular (glanded) cottonseed meal has lower digestibilities of protein and amino acids than soybean meal.

3. Canola, peanut, and sunflower meals appear to have digestibility values between those of soybean and cottonseed meals.

4. Amino acid digestibilities are lower in meat and bone meal and corn-gluten feed than in soybean meal. Tryptophan digestibility is unusually low, which has added significance since the tryptophan content of these ingredients is very low.

Use of Ileal Digestibility Values in Formulating Diets

The important question is: "Can ileal digestibility values help in formulating practical diets more precisely?" Based on data to this point, the following guidelines appear valid:

1. If only corn and soybean meal are used in formulating diets, the use of total or digestible amino acid values will not improve accuracy over formulation on a protein basis because the NRC requirements

Table 4. Ileal digestibilities (apparent) of protein, lysine, tryptophan, and threonine in selected swine feedstuffs.

	Protein	Lysine	Tryptophan	Threonine
	Percent			
Grains & by-products				
Corn	82	77	70	77
Sorghum	81	75	78	78
Barley	75	73	73	69
Oat groats	84	82	81	78
Wheat	82	76	81	73
Wheat midds	70	74	70	55
Corn gluten feed	51	40	32	46
High-protein feeds				
Soybean meal, 44%	78	86	81	76
Soybean meal, 48.5%	80	85	80	76
Blood meal, ring-dried, 87.8%	87	92	89	87
Canola meal	69	73	71	66
Cottonseed meal, solvent 41%	72	56	72	61
Glandless cottonseed meal	80	77	79	76
Fish meal	78	84	72	82
Meat & bone meal	65	66	54	54
Peanut meal	73	66	74	61
Poultry by-product meal	76	86	79	75
Skim milk, dried	86	94	–	84
Sunflower meal, 34%	73	78	76	70

have been determined largely by feeding corn-soybean meal diets supplemented with crystalline amino acids. Therefore, the requirements compensate for digestibilities of amino acids in corn and soybean meal.

5. The wide variations in ileal amino acid digestibilities among other high protein feedstuffs (blood meal, cottonseed meal, meat and bone meal, canola meal, sunflower meal, peanut meal, etc.) suggest that the use of ileal values may enable more low-quality ingredients to be used in formulating diets and still allow excellent performance.

6. Use of ileal values may improve the precision of diet formulation when high fiber milling by-products (wheat midds, wheat offal, corn gluten feed, corn bran, rice bran, etc.) are used.

7. Ileal digestibility values can also help in formulating diets when the level of soybean meal is reduced to a minimum and crystalline amino acids are added. This possibility will become increasingly important as feed-grade tryptophan and threonine become available at economical prices.

Use of Crystalline Amino Acids in Practical Diets

To maximize lean growth, pig diets must provide adequate amounts of the ten essential amino acids and enough total nitrogen for synthesis of the nonessential amino acids. It makes little difference to the pig whether the amino acids are added to the diet as crystalline amino acids or are obtained from digestion of feed protein in the small intestine.

Research has demonstrated that the amount of soybean meal needed in a diet can be reduced significantly if crystalline L-lysine is added. In formulating such diets, add only enough soybean meal to meet the requirement for the second-limiting amino acid, and then add crystalline lysine to meet the lysine requirement. Pig performance on the reduced-protein, lysine-supplemented diets has been essentially the same as that obtained with normal protein levels. *It is generally accepted that the protein levels of corn-soybean meal starter, grower and finisher diets can be reduced two percentage units and obtain the same pig performance when crystalline lysine is added.* The best current estimates of dietary requirements for conventional and reduced-protein, lysine-supplemented corn-soybean diets for different weights of young and growing-finishing pigs are shown in Table 5.

Remember that the lysine requirement, expressed as a percentage of the diet, decreases with the reduction in dietary protein level. Illinois workers suggest that the lysine requirement decreases by .02% for each 1% decrease in dietary protein level.

As a thumb rule, 3 lb. of lysine · HCl (78.4% L-lysine) and 97 lb. of grain can replace 100 lb. of 44% soybean meal per ton of diet. From an economic standpoint, it is advantageous to use crystalline lysine when 3 lb. of lysine· HCl and 97 lb. of grain can be purchased for less than 100 lb. of soybean meal. However, in actual practice, the cost difference needs to be fairly wide to justify changing diet mixing procedures.

The next obvious question is how much further can the crude-protein content of the diet be reduced before the second-limiting amino acid becomes deficient? A comparison of the amino acid profile of corn-soybean meal diets for growing-finishing pigs with recommended amino acid levels in Table 1 indicates that soybean meal can be reduced substantially *if lysine, tryptophan, and threonine* are added to correct specific deficiencies. The availability and cost of crystalline tryptophan and threonine at the present time make their use questionable from an economic standpoint, but several experiment stations have demonstrated excellent performance when lysine, tryptophan, and threonine are added to reduced-protein diets. Researchers at the Universities of Illinois and Kentucky obtained similar pig performance when the protein levels of starter and grower diets were decreased by four percentage units and crystalline amino acids were added (Table 6).

Table 5. Dietary requirements for pigs using conventional and reduced-protein, lysine-supplemented corn-soybean diets.[a]

	Conventional diets		Reduced-protein, lysine-supplemented diets	
	Protein,%	Lysine,%	Protein,%	Lysine,%
Early Wean (11-22 lb.)	20	1.15	18	1.11
Starter (22-44 lb.)	18	0.95	16	0.91
Grower (44-110 lb.)	16	0.70	14	0.66
Finisher I (110-170 lb.)	14	0.60	12	0.56
Finisher II (170-240 lb.)	13	0.50	11	0.46

[a]Supplemental lysine must be added to achieve the lysine requirement at this level of protein in corn-soybean meal diets. For sorghum-soybean meal finisher diets I and II, the low-protein levels should be increased by one percentage unit.

Supplementation of finishing diets in which protein has been reduced by four percentage units has not been thoroughly investigated. Undoubtedly, lysine, tryptophan, and threonine will be needed as supplements, but more nonspecific nitrogen may also be required to enable the pig to synthesize the nonessential amino acids. Moreover, when soybean meal is replaced by grain and crystalline amino acids, the calcium and phosphorus levels need to be reformulated.

It is unclear how far the industry can go in replacing soybean meal with crystalline amino acids. It depends primarily on the relative prices of the various amino acids, soybean meal, and grain. Recent improvements in the technology for the industrial production of amino acids have stimulated great interest in this area. It is one of the most exciting frontiers in amino acid nutrition.

Table 6. Quantities of crystalline amino acids added to diets with lower protein levels.

Period	Protein level decreased from:	Amounts of crystalline amino acids added:
Starter (10-40 lb.)	18% to 14%	.5% L-lysine · HCl .05% L-tryptophan .13% L-threonine
Grower (40-100 lb.)	16% to 12%	.38% L-lysine · HCl .03% L-tryptophan .10% L-threonine .10% methionine

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