pork industry handbook

MICHIGAN STATE UNIVERSITY EXTENSION

Protein and Amino Acids for Swine

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Authors:
Virgil W. Hays, University of Kentucky
David H. Baker, University of Illinois

Reviewers:
Palmer Holden, Iowa State University
William Luce, Oklahoma State University
Tom R. Carr, University of Illinois

One of the more challenging tasks in formulating swine diets is to provide the optimum level of each of the amino acids for maximum lean growth and reproductive performance at the least cost. To formulate diets effectively, one needs accurate information on: 1. the amino acid requirements for each of the different classes of pigs; 2. the amino acid composition of the available feedstuffs; 3. the biological availability of the amino acids in the feeds used; and, 4. the inherent capacity of the pigs to produce (lean growth potential, litter size potential, milk production level, etc.). 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.

This factsheet considers 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 crude protein to indicate the adequacy of a mixed feed with unknown ingredients to meet the amino acid needs of pigs is of little value. The content of essential amino acids is a much better indicator 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 21 different amino acids. Ten of these must be supplied at optimum levels in the pig's diet. These ten (arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine) are classified as dietary essentials. Two other amino acids (cystine and tyrosine) are classed as semi-essential. Cystine can be synthesized, if an adequate amount of methionine is present; and, tyrosine can be synthesized, if an adequate amount of phenylalanine is present. The other nine amino acids (aspartic acid, asparagine, glutamic acid, glutamine, glycine, alanine, proline, hydroxyproline, and serine) are classed as dietary nonessentials. They are metabolically essential in that they are component parts of tissue and milk proteins; but, they can be synthesized at sufficient rates provided an adequate amount of nitrogen is present in the diet.

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. Adequate amounts of nonspecific nitrogen to synthesize the non-essential amino acids.

Diets formulated from natural feedstuffs that satisfy the essential amino acid requirements will contain adequate amounts of the nonessential amino acids or nonspecific nitrogen to meet the total protein requirements of the pigs.

The fallacy of using crude protein content of a mixed feed with unknown ingredients as an indicator of amino acid adequacy is shown in Figure 1. This figure illustrates the ability of a 16% protein corn-soybean meal diet, a 16% protein corn-meat and bone meal diet and a 16% corn-peanut meal diet to meet the growing pig's (45 lb to 110 lb) requirement for lysine, tryptophan and threonine (the three most limiting amino acids in U.S. diets). The solid portion of the bars show the contribution of corn in meeting the requirements for lysine (27%), tryptophan (33%) and threonine (49%). The diagonally lined portions

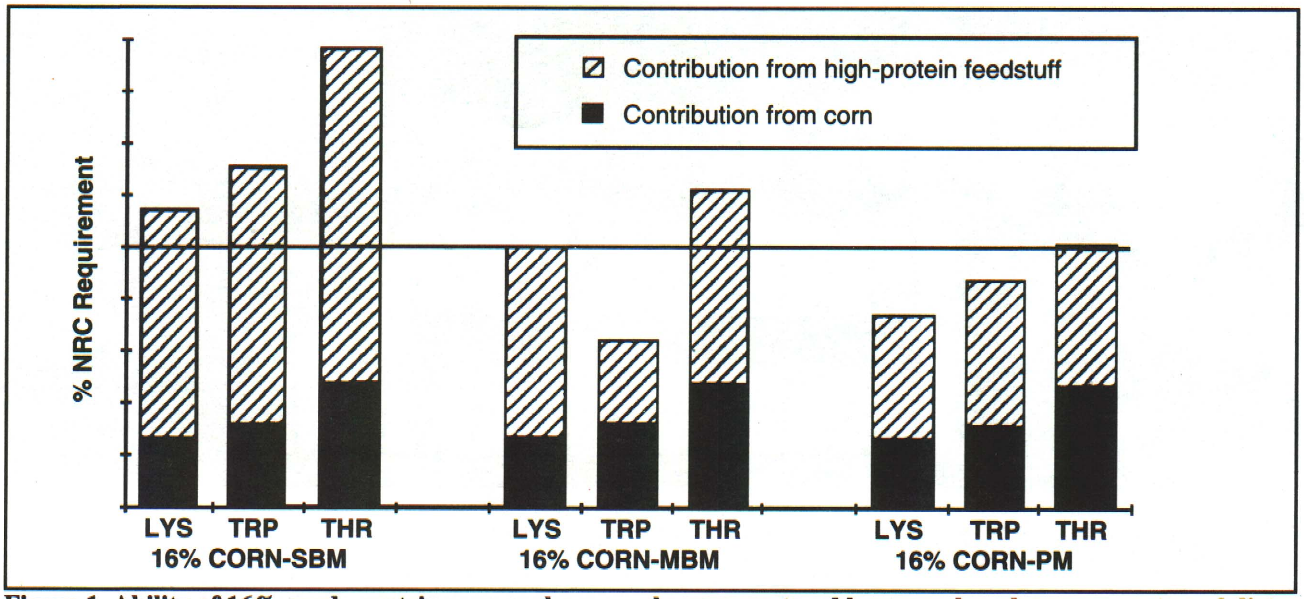

Figure 1. Ability of 16% crude protein corn-soybean meal, corn-meat and bone meal, and corn-peanut meal diets to meet the lysine, tryptophan, and threonine requirements of the growing pig.

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 requirement of 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 is inadequate in both lysine and tryptophan and barely adequate in threonine. This illustrates clearly that crude-protein content of a mixed feed is an unreliable indicator of amino acid adequacy of the feed unless one knows the feedstuffs used in preparing the feed. If a crude protein content of 8.5% is used for corn and sorghum in formulating diets, the crude-protein content of a corn-soybean meal or sorghum-soybean meal 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 or cereals other than grain or sorghum, the crude protein level must be adjusted to provide adequate levels of each of the essential amino acids.

Concepts of Amino-Acid Nutrition

1. Protein synthesis is limited to that permitted by the most limiting amino acid. If any one of the essential amino acids needed to synthesize 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 the lowest stave, a feed protein will only allow a pig to synthesize lean tissue to the level supported by 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 is 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 is amount of protein.

2. Amino acid requirements, when expressed as a percentage of the diet, are truly moving targets because of the many factors that affect "the requirements". The most important factors are:

A. Energy density of the diet—feed intake is reduced as energy density of the diet increases; thus amino acid requirements (% of diet) increase as energy density increases.

B. Stage of development—requirement is higher for the young rapidly growing pig (relative to body weight) than for more mature animals.

C. Genetic potential—requirement is higher for animals with higher levels of lean growth, more pigs per litter or higher levels of milk production.

D. Sex—requirement is highest for boars, intermediate for gilts and lowest for barrows because of the differences in lean relative to fat deposition and the differences in feed intake.

E. Criteria used in establishing requirement—requirement is higher for maximizing efficiency of feed conversion or leanness of carcass than it is for maximizing rate of body weight gain.

F. Interrelationships among amino acids—cystine can provide approximately 50% of the requirement for sulfur amino acids (methionine + cystine). Tyrosine can provide approximately 50% of the phenylalanine + tyrosine requirement.

G. Environmental temperature—as feed intake is influenced by environmental temperature, amino acid concentrations in the diet may need altering to maintain adequate daily intake of the essential amino acids.

3. Pigs utilize the L-isomer (the isomeric form found in all feedstuffs or synthesized by microbial fermentation) of all amino acids. Crystalline amino acids produced by chemical synthesis are a mixture of the D- and L- isomers. Pigs utilize the D-forms of methionine and tryptophan quite effectively. D-methionine is equal or near equal to the L-form in biological value, and the DL-isomer of

Table 1. Recommended Dietary Levels (%) of Amino Acids for Growing Pigs

Ratio (AA/Lysine)				Weight Range, lb [a]				
Amino Acid	11-45 lb	45-110 lb	110-265 lb	11-22	22-45	45-110	110-175	175-265
Lysine [b]								
Mixed Sex	1.00	1.00	1.00	1.55	1.15	0.85	0.72	0.60
Barrows	1.00	1.00	1.00	1.55	1.15	0.85	0.68	0.58
Gilts	1.00	1.00	1.00	1.55	1.15	0.85	0.76	0.62
Mixed Sex [c]								
Tryptophan	0.17	0.18	0.19	0.26	0.20	0.15	0.14	0.11
Threonine	0.65	0.67	0.70	1.01	0.75	0.57	0.50	0.42
Met. + Cys.	0.60	0.62	0.64	0.85	0.69	0.53	0.46	0.39
Histidine	0.32	0.32	0.32	0.50	0.37	0.27	0.23	0.19
Leucine	1.00	1.00	1.00	1.55	1.15	0.85	0.72	0.60
Isoleucine	0.60	0.60	0.60	0.93	0.69	0.51	0.43	0.36
Valine	0.68	0.68	0.68	1.05	0.78	0.58	0.49	0.41
Phe. + Tyr.	0.95	0.95	0.95	1.47	1.09	0.81	0.68	0.57
Arginine	0.42	0.30	0.18	0.65	0.48	0.26	0.13	0.11
Crude Protein [d]				25.7	20.7	16.8	15.0	13.2

[a] Should one wish to make more frequent diet changes, adjust the lysine level up for the first third of the weight bracket and down for the last third. For example, for the 110-175 lb bracket: feed 0.76% lysine from 110 to 130 lb, 0.72 from 130-150 and 0.68% from 150-175. Use the amino acid ratios presented in column 3 to calculate the needed levels of other amino acids.

[b] The values presented are for pigs having a moderate lean (lean with 10% fat) growth potential (0.6 to 0.7 lb/day); housed in environmental temperatures near the comfort zone; and, fed a diet containing approximately 1475 kcal ME/lb. Adjustments may be needed for conditions that differ from these standards, i.e. (1) For pigs having a high (0.8+) or low (0.5-) lean growth potential , increase or decrease the lysine values for the 45 to 265 stages by 10%. The lysine level for the 45 to 110 lb weight period for mixed sexes would be approximately 0.94 and 0.76% for the high and low lean growth potential, respectively. (2) If the energy content of the diet is higher or lower, multiply the tabular lysine values by the energy level of the diet(kcal ME/lb) divided by the standard energy value (1475 kcal/lb) In each case, the needed level of the other amino acids may be calculated by multiplying the revised lysine level by the appropriate lysine:AA ratio as presented in columns 1-3.

[c] The values presented for amino acids other than lysine are for feeding barrows and gilts together. For feeding the individual sexes, multiply the appropriate lysine level for that sex and weight bracket (columns 4-8) by the appropriate amino acid ratio in columns 1-3. e.g. the appropriate tryptophan level for 110-175 lb gilts would be 0.19 x 0.76 = 0.144. If adjustment is made in lysine level, revised estimates for other amino acids must be calculated.

[d] Approximate crude protein (% of diet) necessary to meet the lysine needs, which would be the first limiting amino acid in diets including corn and soybean meal as the major ingredients.

methionine hydroxy analog is also well utilized. D-tryptophan has 70% to 90% of the biological value of L-tryptophan. The D- isomers of lysine and threonine are not utilized by the pig.

4. A deficiency of even one essential amino acid causes a reduced feed intake and a reduction in performance. The effect on performance of an excess of one or more amino acids depends on the severity of the excess and the form in which it is provided. The harmful effects of an excess varies between amino acids and is greater if the excess is in the free form. Moderate excesses in natural proteins have little or no detrimental effects on feed intake or growth rate.

These concepts provide guidelines that must be considered when attempting to generalize about the protein and amino acid needs of swine to optimize reproductive efficiency, growth, feed conversion, carcass merit and production costs.

Amino-Acid Requirements

Requirements for the essential amino acids at different weights of growing-finishing pigs are shown in Table 1. In all cases, the requirements refer to the amount of L-isomer required. The values in Table 1 are based on published experimental data providing estimates of the dietary levels that will result in optimum performance. Since data are limited for certain stages of the production cycle; genetic potential of pigs vary widely among herds; environmental conditions vary among experiments; the amount of information available varies greatly among amino acids; and, the estimated requirements vary among experiments, the voids have been filled and the averages adjusted using the "Ideal Amino Acid Pattern" concept.

The ideal amino acid patterns are presented in the first three columns of Table 1. Values in the ideal pattern were arrived at by relating the requirement of each of the amino acids to the level of lysine required. Lysine is used as the base value as more information is available on the dietary requirement for lysine than for any other amino acid. Thus, for the other amino acids the value is expressed as a percentage of the lysine requirement. The percentage values for the other amino acids are based on a combination of experimental data on estimated requirement relative to lysine and on whole body amino acid compo-

Table 2. Recommended dietary amino acid levels (%) for breeding swine.

Amino Acid	Bred Gilts and Sows and Breeding Boars	Lactation[a]	Growing Boars[b] Weight Range		
			45-110	110-175	175-265
Lysine, %	0.60	0.90	0.94	0.84	0.68
Tryptophan, %	0.12	0.16	0.18	0.16	0.13
Threonine, %	0.40	0.60	0.63	0.59	0.48
Meth. + Cys., %	0.40	0.55	0.58	0.54	0.44
Histidine, %	0.20	0.30	0.30	0.27	0.22
Leucine, %	0.60	0.90	0.94	0.84	0.68
Isoleucine, %	0.40	0.50	0.56	0.50	0.41
Phen. + Tyr., %	0.60	0.90	0.64	0.57	0.46
Valine, %	0.42	0.60	0.89	0.80	0.65
Arginine, %	0.00	0.27	0.28	0.15	0.12
Protein, %[c]	13.0	17.0	18.0	17.0	15.0

[a] For lactating sows consuming 14 or more lb of feed per day.

[b] For growing boars of moderate lean growth potential and moderate environmental temperatures. For different weight categories and different weight ranges use recommended amino acid ratios for the specified weights and the lysine levels for gilts plus 10% to calculate levels for boars.

[c] Approximate protein level required to meet lysine needs.

sition of pigs. The relative values arrived at by feeding trials and by whole body composition are remarkably similar.

Most estimates of the requirements have been determined using corn-soybean meal diets containing about 1425 kilocalories of metabolizable energy/pound. Therefore, they may need modification if other feed ingredients are used, especially if there are appreciable differences in amino acid availability 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 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 (lean tissue) in the weight gained is higher than during the finishing period. These changes in rate of growth and protein-fat composition of the growth are the basis for recommending different dietary protein levels to meet the amino acid requirements for different stages of the life of the pig. From a practical standpoint, any combination of natural feedstuffs that supplies adequate quantities of the four most limiting amino acids (lysine, tryptophan, threonine and methionine) will also provide adequate amounts of the other essential and non-essential amino acids needed to optimize weight gain and feed efficiency of growing-finishing pigs.

Requirements for pregnant gilts and sows (Table 2) are based on the amounts required for satisfactory nitrogen (protein) retention during the later stages of pregnancy. Requirements are relatively low during gestation because sows deposit approximately 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 by drawing on their own body stores. Feeding deficient levels of protein or individual amino acids during gestation appears to have little effect on number of pigs farrowed but reduces lactation and rebreeding performance. Therefore adequate levels of amino acids (protein) must be fed during gestation to optimize lactation and reproduction.

The requirements for lactation (Table 2) have been determined experimentally or have been extrapolated from published requirements for maintenance of adult sows plus amounts calculated to support a high level of milk production. Grain-soybean meal diets containing 16% to 17% protein should provide adequate amounts of all essential amino acids for lactation. However, to optimize milk yield and rebreeding performance, adequate feed intake is essential. Older sows should consume 13 lb to 15 lb or more of feed per day while first litter sows usually consume 2 lb to 4 lb less per day.

Amino Acids in Grain

Although cereal grains are considered primarily for their contribution of energy, they also contribute protein and amino acids. The essential amino acid composition of corn and sorghum hybrids are quite similar as shown in Table 3. Compared to the finishing (110 to 265 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 finishing stage, both grains contain adequate amounts of arginine, histidine, leucine and phenylalanine plus tyrosine. Both are deficient in lysine, tryptophan, threonine, total sulfur amino acids, isoleucine, and valine.

Oats, wheat and barley are higher in protein than corn; but, they contribute little 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, methionine and cystine. 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

Table 3. 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	8.3	.26	.05	.28	.34	.28	.39	.99	.23	.37	.64
Sorghum	9.2	.22	.10	.31	.34	.37	.46	1.21	.23	.38	.84
Barley	11.3	.41	.11	.35	.40	.39	.52	.77	.25	.54	.84
Oats	10.8	.53	.14	.44	.44	.48	.66	.92	.31	.87	1.06
Wheat	13.5	.34	.15	.37	.40	.41	.54	.86	.32	.60	.98
Corn, high lysine	9.5	.35	.07	.35	.32	.33	.47	.93	.33	.60	.78
Protein Sources[d]											
Soybean meal	43.8	2.83	.61	1.73	1.22	1.99	2.06	3.42	1.17	3.23	3.87
Soybean meal	47.5	3.02	.64	1.69	1.34	2.16	2.27	3.66	1.28	3.48	4.21
Alfalfa meal, dehydrated	17.0	.74	.24	.70	.43	.68	.86	1.21	.37	.71	1.39
Blood meal, spray or ring-dried	86.5	7.45	1.48	3.78	1.98	1.03	7.03	10.81	5.30	3.69	8.52
Canola meal, solvent	35.6	2.08	.45	1.59	1.48	1.43	1.82	2.58	.96	2.21	2.56
Corn gluten feed	21.5	.63	.07	.74	.70	.66	1.01	1.96	.67	1.04	1.34
Cottonseed meal, solvent	41.4	1.72	.48	1.36	1.34	1.30	1.78	2.47	1.17	4.55	3.42
Distillers dr. solubles (corn)	26.7	.82	.23	1.03	.97	1.21	1.50	2.25	.66	.90	2.18
Fish meal (Menhaden)	62.9	4.81	.66	2.64	2.34	2.57	3.03	4.54	1.78	3.66	4.55
Meat Meal	55.1	3.07	.44	1.97	1.40	1.60	2.66	3.84	1.39	3.60	3.57
Meat & bone meal	49.1	2.51	.28	1.59	1.18	1.34	2.04	2.98	.91	3.45	2.69
Peanut meal, solvent	49.1	1.66	.48	1.27	1.04	1.78	1.98	2.83	1.06	5.09	4.15
Skim milk, dried	33.9	2.80	.50	1.59	1.19	1.83	2.28	3.59	1.03	1.21	3.58
Sunflower meal	42.2	1.20	.44	1.33	1.48	1.20	1.74	2.31	.92	2.93	2.69
Wheat bran	15.7	.64	.22	.52	.50	.49	.72	.98	.44	1.07	1.05
Wheat midds, standard	15.9	.57	.20	.51	.52	.53	.75	1.06	.44	.97	.99
Whey, dried whole	11.7	.87	.17	.70	.32	.60	.58	1.05	.22	.25	.59
Yeast, brewers dried	45.9	3.22	.56	2.20	1.24	2.15	2.39	3.13	1.09	2.20	3.38

[a]All values on an as fed basis.
[b]Effective total methionine + cystine 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 phenylalanine + tyrosine acid value. If tyrosine content was higher than phenylalanine, it was reduced to phenylalanine content since tyrosine can provide only 50% of the total phenylalonine + threonine requirement.

Table 4. Lysine, tryptophan, threonine and methionine content (%) of selected feedstuffs and of the protein of selected feedstuffs.

	Lysine %		Tryptophan %		Threonine %		Methionine %	
Ingredient	**Feed**	**Prot.**	**Feed**	**Prot.**	**Feed**	**Prot.**	**Feed**	**Prot.**
Blood meal (ring-dried 85)	7.45	8.61	1.48	1.71	3.78	4.37	1.98	2.29
Fish meal (Menhaden, 60%)	4.81	7.89	0.66	1.08	2.64	4.33	2.34	3.84
Skim milk, dried (32%)	2.80	8.26	0.50	1.47	1.60	4.72	1.19	3.51
Whey, dried whole (12%)	0.87	6.90	0.17	1.45	0.70	5.98	0.32	2.86
Soybean meal (44%)	2.83	6.46	0.61	1.39	1.69	3.86	1.22	2.79
Soybean meal (48.5%)	3.02	6.36	0.44	1.35	1.73	3.54	1.34	2.82
Meat meal (55%)	3.07	5.58	0.44	0.80	1.97	3.58	1.40	2.55
Meat and bone meal (50%)	2.51	5.11	0.28	0.57	1.59	3.23	1.18	2.40
Cottonseed meal (41%)	1.72	4.20	0.48	1.17	1.36	3.31	1.34	3.27
Peanut meal (49.1%)	1.66	3.38	0.48	0.97	1.27	2.59	1.04	2.11
Corn gluten feed (22%)	0.63	2.93	0.07	0.33	0.74	3.44	0.70	3.26
Feather meal (85%)	1.62	2.39	0.54	0.54	3.82	4.70	1.22	1.50

effective way to take advantage of the superior amino acid content of oats, wheat and barley is to balance the diets on an amino acid basis rather than a protein basis. Even though sorghum generally contains slightly more protein than does corn, the same amount or more of the high protein feedstuff must be fed because the amount of lysine is usually slightly lower in sorghum than in corn (Table 3). 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. To date the lysine and tryptophan levels in "high Lysine" or "opaque-2" corn have been quite variable. One must have reliable estimates of amino acid, especially lysine and tryptophan, content to effectively take advantage of the improved protein quality in the "high lysine" corn varieties. Studies have indicated that commercially high lysine corn contains 25% 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 4 gives the lysine, tryptophan and threonine content of several high-protein feed stuffs. High-protein feedstuffs vary widely in percentage of protein. Therefore, the amino acid content expressed as a percent of protein in combination with total protein content is a good standard to use when evaluating the ability of a protein source to correct the amino acid deficiencies of grain without providing a large excess of the essential amino acids in the diet. In formulating a 16% protein grower (45 to 110 lb) 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, 6.8%; tryptophan, 1.2%; and, threonine, 3.7%.

Values in Table 4 indicate that only blood meal, fish meal, dried skim milk and soybean meal plus adequate level of total protein to complement the grains satisfy all the amino acid requirements. The available tryptophan content of blood and fish meals may be their limiting factor, while the low protein content of dried whey limits its use. Moreover, the supply and price of blood meal, fish meal and milk products limits their routine use in swine feeds.

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 feedstuffs in Table 4 are very deficient in lysine. These include: cottonseed meal, peanut meal, feather meal, and corn gluten feed. Each of these can effectively provide a portion of the protein supplement, but they must be used in combination with other high protein feedstuffs and/or synthetic amino acids to assure that the mixture contains adequate amounts of the limiting amino acids to correct the deficiencies in grains. Cottonseed meal contains an inhibitory substance (gossypol) which further limits its usefulness.

Table 5. Ileal digestibilities (apparent) of protein, lysine, tryptophan and threonine in selected feedstuffs.

Feedstuff	Lysine	Tryptophan	Threonine	Methionine
	Percent digestible			
Grain & by-products				
Corn	78	84	82	90
Sorghum	81	83	84	89
Barley	79	80	81	86
Oat Groats	79	82	80	86
Wheat	81	90	84	90
Wheat midds	89	91	88	93
Wheat bran	71	74	70	79
Corn gluten feed	66	64	71	79
High-protein feeds				
Soybean meal, 44%	89	87	85	91
Soybean meal,48.5%	90	90	87	91
Blood meal, ring dried, 87.8%	94	94	94	96
Canola meal	78	75	76	86
Corn gluten meal	80	63	84	90
Cottonseed meal, solvent, 41%	64	65	68	75
Cottonseed meal, glandless	80	77	79	76
Fish meal	95	90	88	94
Meat and bone meal	80	78	80	83
Peanut meal	88	—	90	89
Poultry by-produce meal	80	—	77	77
Skim milk, dried	93	97	92	96
Sunflower meal, 34%	81	84	82	91

Consideration of Amino-Acid Digestibilities in Formulating Diets

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 continues to be directed toward determining amino acid digestibilities. Most of the data obtained in the 1960's and early 1970's represented digestibilities measured over the total digestive tract. These apparent digestibility (amount consumed in the diet/amount in the feces/amounts consumed in the diet) values have been used extensively in formulating diets. However, more recent experiments have shown that most of the protein that disappears from the large intestine is not used effectively by the pig. In recent years, researchers have focused on determining digestibilities at the end of the small intestine (terminal ileum) before the digesta enters the large intestine.

A summary of the ileal digestibilities of lysine, tryptophan, threonine, and methionine in several grains and high protein feedstuffs is given in:

Table 5. Although data are incomplete at present, some generalizations can be made. 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 bran and corn gluten feed are considerably lower than the grains. Wheat bran also is relatively rich in total lysine, tryptophan and threonine compared to other grains; therefore, the use of ileal digestibility values for these products may improve the precision of diet formulation.

Differences in digestibilities among high-protein feedstuffs are much greater than among 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 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 is lower in protein and amino digestibility than soybean meal.
3. Canola, peanut and sunflower meals appear to have digestibility values between those of soybean meal and cottonseed meal.
4. Amino acid digestibilities are lower in meat and bone meal and corn-gluten meal than in soybean meal. Tryptophan digestibility is unusually low which has added significance since the tryptophan content of these ingredients also is very low.

Use of Ileal Digestibility Values in Formulating Diets

Ileal digestibility values can improve the precision of formulating practical diets as more accurate data becomes available. Based on data to this point, the following guide lines appear valid:

1. If only corn and soybean meal are used in formulating diets, the use of digestible amino acid values will not improve the accuracy over formulation on a protein or total amino acid basis since the amino acid requirements have been determined largely by feeding corn-soybean meal diets. Therefore, the estimated requirements compensate for digestibilities of amino acids in corn and soybean meal.
2. The wide differences in ileal amino acid digestibilities among 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 effective use of alternative protein sources and still allow excellent performance.
3. 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.
4. Ileal digestibility values of grains may also help in formulating diets when the level of soybean meal is reduced to a minimum and crystalline amino acids are added. This may be increasingly important as feed-grade tryptophan and threonine and possibly other amino acids become economically competitive.
5. It is important to realize there is considerable variation in estimates of ileal digestibility of feedstuffs. There is wide within and between laboratory variation in amino acid analyses. The methodologies (among pig variation, surgical cannulation of pigs, sample collection, etc.) necessary to attain ileal digestibility contribute further to the variation.

Use of Crystalline Amino Acids in Practical Diets

To maximize lean growth, pig diets must provide adequate amounts of the essential amino acids and enough total nitrogen for synthesis of the nonessential amino acids.

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 approximately two percentage units and obtain the same pig performance when crystalline lysine is added.

As a thumb rule 3.4 lb of lysine HCl (78.4% L-lysine) and 96.6 lb of grain can replace 100 lb of soybean meal (44% protein). From an economic standpoint, it is advantageous to use crystalline lysine when the 3.6 lb of lysine HCl and 96.4 lb of corn costs less than 100 lb of soybean meal.

The obvious question is how much further can the crude protein content of the diet be reduced before other amino acids become deficient. A comparison of the

Table 6. Illustration of similar performance by feeding amino acid supplemented diets that were reduced two of four percentage units of protein.

Protein	Adequate	Low	Low + Amino Acid(s)
Protein adequate or reduced two percentage units [a]			
Daily gain, lb.	1.62	1.47	1.64
Daily feed, lb.	5.01	5.10	5.03
Feed/gain	3.09	3.47	3.07
Protein adequate or reduced four percentage units [b]			
Daily gain, lb.	1.63		1.64
Daily feed, lb.	4.99		5.03
Feed/gain	3.06		3.07

[a] Two experiments involving 78 pigs/treatment and weighing 42-227 lb. Adequate protein = 17% in grower, 15% in developer and 13% in finisher. Reduced protein = 15%, 13% and 11% during the three stages, respectively. Lysine was added (0.15%) to the Low plus amino acid diet to equal the total lysine level in the adequate diet.

[b] Seven experiments involving growing (37-45 lb), finishing (117-207 lb) and growing-finishing (46-240 lb), 184 pigs/treatment. Adequate protein = 16-17% in grower, 14-15% in developer and 13-14% in finisher. Low protein plus amino acids group were fed diets four percentage units lower in protein in each stage and supplemented with 0.3% lysine, 0.05 to 0.10% threonine and 0.03 to 0.05% tryptophan and 0.5 to 0.10% methionine.

amino acid profile of corn-soybean meal diets for growing-finishing pigs with recommended amino acid level in Table 1 indicates that soybean meal can be reduced substantially if lysine, tryptophan and threonine are added to correct specific deficiencies.

Several experiment stations have demonstrated excellent performance when lysine, tryptophan and threonine are added to reduced protein diets.

Table 6 illustrates that similar performance can be realized when corn and synthetic lysine are substituted for soybean meal in corn-soybean meal type diets provided the reduction in protein level is no more than two percentage units. Further reduction in protein results in other amino acids becoming limiting. Table 6, also, illustrates that supplementing with tryptophan, threonine and methionine will allow a further reduction of two additional (a total of four) percentage units of protein. Though quite satisfactory results have been obtained when corn and amino acids are substituted for soybean meal, further work is need to evaluate similar substitutions among other grains and other protein sources.

It is unclear how far the industry can go in replacing high-protein ingredients with grains and supplemental amino acids. From the economic viewpoint, it will depend on the relative prices of the various amino acids, the high protein feedstuffs and the grains. It must be kept in mind that substituting grain and amino acids for high-protein feedstuffs alters levels of other nutrients (macro and micro minerals, fatty acids and vitamins) in the diet. Appropriate adjustments in these other essential nutrients may be necessary to maintain maximum performance.

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