3. NUTRIENTS

Although diets are mixed using ingredients, what really matters to a pig are the nutrients contained in those ingredients. The relative proportions of barley, wheat, soybean meal, and other feedstuffs in a diet are determined on the basis of the nutrients they provide to a pig. When a nutritionist formulates a diet for pigs, no less than 41 essential nutrients are considered.

In this chapter, the utilization of nutrients by pigs and means to estimate the available nutrient levels in pig feed ingredients are discussed. For information on nutrient allowances in diets for the various classes of pigs, the reader is referred to chapters 6 - 9. Water, which can also be classified as a nutrient, is addressed in chapter 12.

What is a Nutrient?

Knowing the difference between a nutrient and an ingredient, or feedstuff, is critical when formulating a diet. A nutrient is a chemical substance that is supplied by the diet and which pigs need to stay alive. Nutrients perform specific functions in the body and their absence or deficiency will result in reduced productivity, health problems and, possibly, death.

An ingredient or feedstuff is the material used to supply nutrients. For example, barley and corn are ingredients which contain amino acids, energy, and other nutrients. They can supply a pig with some of the nutrients it needs. A balanced diet mixes ingredients, such as corn or barley, that supply the nutrients in proper proportions. The pig has no specific requirement for individual ingredients — it does not need barley or corn, specifically, in its diet, for it can obtain the necessary nutrients from other ingredients, such as canola or soybean (or in some countries, even green bananas!). A pig may prefer to eat one ingredient over another, but ingredients have no unique role in a pig's diet. Selecting the type of feedstuffs to supply nutrients is much less critical than making certain the necessary nutrients are supplied from the feedstuffs chosen.

The essential nutrients can be divided into categories of minerals, amino acids, vitamins, fatty acids, energy, and water (Table 3-1). If a diet is to be properly balanced, the nutritionist must know the pig's requirement for each nutrient and the amount supplied by each ingredient.

Table 3-1. Essential Nutrients in the Diet of a Pig.

Amino Acids	Minerals	Vitamins	Other
Arginine	Macro	Vitamin A	Energy
Histidine	Calcium	Vitamin D	Linoleic Acid
Isoleucine	Chloride	Vitamin E	(Omega-6 fatty acids)
Leucine	Magnesium	Vitamin B_{12}	Water
Lysine	Phosphorus	Biotin	
Methionine	Potassium	Choline	
Phenylalanine	Sodium	Folic Acid	
Threonine	Sulphur	Menadione	
Tryptophan		Niacin	
Valine	Micro	Pantothenic Acid	
Cystine*	Cobalt	Pyridoxine	
Tyrosine*	Copper	Riboflavin	
	Iodine	Thiamine	
	Iron		
	Manganese		
	Selenium		
	Zinc		

* These amino acids are considered semi-essential nutrients because they can be derived from methionine and phenylalanine, respectively. Other nutrients, such as vitamin C, linolenic acid, fluorine, chromium, nickel, lead silicon, tin, and vanadium, may be essential in a pig's diet, however, deficiencies are extremely unlikely and/or requirements for these nutrients have not been clearly established.

Nutrient Availability

Availability refers to the pig's ability to digest, absorb, and utilize nutrients from a given ingredient. Very few nutrients are 100% available. A nutrient may be present in an ingredient but not available to the pig for both mechanical (e.g., processing methods) and physiological (e.g., digestive functions, age, state of health) reasons. Defining the availability for each nutrient in each ingredient is a difficult task because availability varies from ingredient to ingredient and is influenced by many factors.

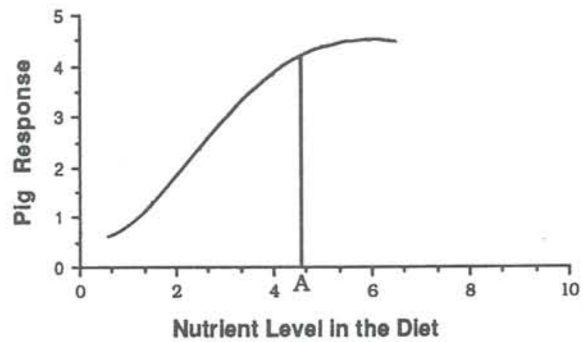
How does the nutritionist work around this problem? In many cases, sufficient information is available to permit at least an educated guess. Diets will often include more than one basal grain and more than one protein supplement. Thus, the nutritionist 'hedges his position' across a number of ingredients, such that underestimating one might be compensated by overestimating another. This approach is not a totally desirable one, but until more precise data becomes available, it is probably the most practical one.

Nutrient Requirements

What is meant by the word 'requirement' from a nutritionist's perspective? Traditionally, a requirement has been defined as the amount of a given nutrient a pig requires to **maximize** performance. Producers need to understand the criteria used to determine requirements because how the requirements are determined can influence the way producers use nutritional information.

One of the frustrations in defining a requirement is that maximum performance may occur at different nutrient levels depending on the response criteria being considered. For example, maximum growth rate may require more or less of an amino acid than maximum feed efficiency. The amount of a given nutrient required to maximize the immune response may differ from the amount required for maximum feed intake. If carcass merit is used to evaluate nutrient requirements, conclusions may differ from those reached using growth rate.

Typically, in the case of essential amino acids and many minerals, the requirement is determined by feeding a range of levels of the nutrient and determining the lowest concentration that maximizes growth rate, feed efficiency, or some other response criteria. The key word here is 'maximize'. Often, the pig's response to increasing levels of a nutrient becomes progressively smaller as the requirement level is approached (Figure 3-1); consequently, the cost of the last 10% improvement is much higher than the first 10%.



*As the requirement (point A) is approached, the rate of improvement per unit of nutrient decreases.

Figure 3-1. Pig Response to Level of Nutrient in the Diet.

Thus, requirement defines the level needed to achieve maximum performance but not necessarily maximum profit. Each situation must be evaluated to determine the best (most profitable) feeding strategy.

Although we would all like to have neat, simple tables defining an absolute value, they are not realistically possible. Some compromise must occur. The compromise does not diminish the value or importance of nutrient requirement tables, it merely emphasizes the importance of understanding their origin. Three excellent publications that provide useful requirement guidelines are the National Research Council's *Nutrient Requirements of Swine (1988)* , the Agricultural Research Council's *The Nutrient Requirements of Pigs (1981)*, and the Australian Agricultural Council's *Feeding Standards for Australian Livestock - Pigs (1987)*.

Energy

According to the definition given earlier, energy is not truly a nutrient. Energy is a characteristic of the organic nutrients (carbohydrates, fats, amino acids) that are normally present in the pig's diet. The energy released by burning a substance in a fire is the same as the energy obtained by the body when it metabolizes energy in a cell. The amazing point is that, unlike an open fire which releases all its heat, the body is able to 'capture' the energy that is supplied by the diet and convert at least part of it into forms the cell can use for various purposes. Energy, due to the amount required, is generally the most expensive 'nutrient' in the pig's diet. Consequently, nutritionists focus considerable attention on energy in feed formulation and feeding management in order to minimize feed cost without compromising performance.

Energy Components

The total quantity of energy contained in a feedstuff can be partitioned into different components based on how the pig will use the energy (Figure 3-2). If an ingredient, such as barley or wheat, is burned completely, the amount of energy released is called **gross energy** (GE). The gross energy content can be determined by the bomb calorimeter. GE is thus the total amount of energy contained in the grain; if the pig could digest and utilize 100% of the energy, that is how much would be available. The pig, however, digests or absorbs only a portion of the gross energy. The energy absorbed by the intestinal tract and actually available to the pig is called the **digestible energy** (DE). The DE content of any feedstuff can be determined by measuring the quantity of food (energy) consumed and subtracting the energy lost in the feces (calculated by weighing the feces and analysing their composition).

Gross Energy - Fecal Energy = Digestible Energy

Some of the digestible energy is lost in the pig's urine or released as gas from its gastro-intestinal tract. Much of the energy lost in the urine results from the excretion of unneeded nitrogen compounds, such as urea. The amount of digestible energy remaining in the pig after these losses is called **metabolizable energy** (ME).

Digestible Energy - (urine energy loss + gas energy loss) = Metabolizable Energy

A portion of metabolizable energy is lost when the pig uses the nutrients in the feed as heat, i.e. heat losses during eating, digestion and actual nutrient metabolism. This portion is called the heat increment. Once the heat increment is used up out of ME, the energy actually available to the pig for maintenance and growth is left. This amount of energy is called **net energy** (NE). NE is the best estimate of the amount of useful energy that is supplied by feed ingredients.

Metabolizable Energy - Heat Increment = Net Energy

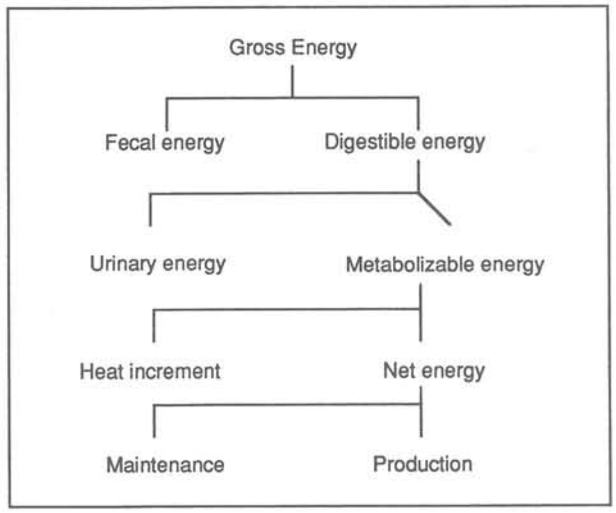


Figure 3-2. Distribution of Dietary Energy.

Some scientists have attempted to use this information on heat increment to practical advantage by designing diets around heat increments. The pig is a warm-blooded animal and must maintain a constant internal body temperature irrespective of the temperature of its surroundings. Normal metabolism generates heat that is used in body temperature regulation. If a pig is chilled, it must eat more feed to keep warm or else it will lose weight or gain it at a slower rate. The heat increment is used to provide some of this required heat, so heat increment in a diet is desirable. The pig will need less heat to maintain a constant body temperature in hot weather and will actually lower its feed intake to reduce the production of metabolic body heat if it is in danger of becoming heat stressed; in this case, heat increment in the diet is detrimental. Obviously, in these two instances, pigs will require diets with different heat increments. The quantity of heat increment varies depending on the nature of the diet.

The solution proposed by some scientists is to feed a diet high in heat increment (rich in fibre) when the pig is likely to be chilled. When the pig is likely to be heat stressed, a diet low in heat increment (rich in fat) is recommended. Under Canadian conditions, this feeding approach means feeding a high-fibre diet to dry sows in chilled conditions, such as in outside housing in winter or in a cool gestation barn (especially barns equipped with individual stalls where sows cannot huddle to keep warm). A high fibre diet is never fed to weanling pigs, lactating sows, or growing pigs because growth rate would suffer. In the heat of summer, lactating sows and growing pigs should receive a diet rich in fat to help maintain energy intake. Of course, these suggestions must be considered in the context of cost and economic benefit.

Although net energy is the best estimate of how much useful energy is supplied by a diet, it is rarely used as a system for formulating swine diets in North America because of the difficulty in routinely and accurately determining the heat increment of feeding when different ingredients are fed to pigs. NE systems are used more commonly in European countries, where a larger variety of ingredients are used to formulate swine diets.

Table 3-2 shows the GE, DE, ME, and NE content in selected pig feed ingredients. Most of the ingredients listed are very similar in GE content. There are, however, some important differences in DE content, both expressed in absolute values as well as in fractions of GE content. In fact, barley contains more GE but less DE than corn. This clearly indicates that it is more accurate to formulate pig diets based on a DE basis rather that on a GE basis.

The proportion of digested energy lost in the urine is fairly constant for all grains and all protein sources, but differs between these classes of ingredients. This difference is due in part to the urinary energy lost during excretion of nitrogenous waste products. Because of the differences between protein sources and grains, there are theoretical advantages to using ME values in preference to DE values to formulate feed. However, note that many of the published ME values have merely been derived mathematically from DE. Direct assays (analyses) of ME are difficult since measuring the amount of energy excreted in the urine poses a number of logistical problems. Whether DE or ME is used, be certain that both requirement and nutrient values are expressed in the same system.

The values in Table 3-2 demonstrate that the differences in NE content between feedstuffs tend to be larger than the differences in DE content. For example, in a DE system, corn contains 12% more energy than barley. In a NE system, this difference increases to 15%. For ingredients with extreme compositions such as alfalfa and wheat shorts (high in fibre) or soybean oil (high in fat), these differ-

Table 3-2. Proportions of Gross Energy (GE), Digestible Energy (DE), Metabolizable Energy (ME) and Net Energy (NE) in a Sample of Ingredients.

	GE	DE	ME	NE	DE:GE	ME:DE	NE:ME
Alfalfa Meal	3830	1880	1705	540	.49	.91	.32
Barley	4395	3120	3040	1980	.71	.97	.65
Corn	3945	3490	3380	2270	.88	.97	.67
Wheat	3965	3360	3200	2215	.85	.95	.69
Wheat Shorts	4060	3025	2835	1795	.75	.94	.63
SBM 47%	4260	3680	3385	1760	.86	.92	.52
Soybean Oil	9395	7560	7280	5500	.80	.96	.76

Derived from: Ewan, 1989; Energy metabolism of farm animals. EAAP publication No.. 43. Pudoc Publishers, Wageningen, The Netherlands.

ences are even more apparent. This again illustrates that, in theory, it is more accurate to formulate diets using an NE rather than DE or ME system.

Energy is measured in units of either calories (cal) or joules (J). The term used in this book is the kilocalorie, equal to 1000 calories. The joule is more common in Europe and is becoming more popular in Canada, but is not yet universally accepted. One calorie equals 4.184 joules.

Energy Sources

Dietary energy is derived from three sources: carbohydrates, fats, and amino acids. The term carbohydrate includes simple sugars and starches, such as table sugar or the starches found in flour, which are all highly digestible. Carbohydrates also include more complex compounds, such as fibre, which is difficult to digest, and thus a poor energy source.

Defining the term **fibre** has been a source of controversy for decades. For the purposes of this book, fibre is defined as the portion of carbohydrate in a diet that cannot be digested by the enzymes produced by a pig. Pigs, like ruminants, rely on bacteria that are present in the digestive tract to utilize dietary fibre. The pig does not have a requirement for fibre *per se*, although it provides a texture in diets that helps digestive processes. Fibre is used to evaluate ingredient quality because it is associated with reduced DE content and impaired utilization of other important nutrients. Therefore, from a nutrient perspective, fibre has a generally negative impact on animal feed quality.

Measuring fibre in feed ingredients is an area of active research. Table 3-3 defines the fibre content of some common ingredients. The complex nature of fibre is illustrated by the number of fibre values defined. Dietary fibre is a Swedish term that includes lignin (a highly indigestible carbohydrate found in such feedstuffs as straw) plus all complex sugars not found in starch.

The detergent system, developed by P.J. van Soest in the United States, differentiates between two kinds of fibre: acid detergent fibre (ADF) and neutral detergent fibre (NDF). NDF includes material in the plant cell wall, notably cellulose, hemicellulose, and lignin, which are essentially indigestible by swine. ADF consists only of cellulose and lignin. ADF and NDF were developed to evaluate forages for ruminant species. They have also been found valuable by swine nutritionists but tend to underestimate the total fibre of cereal grains.

Table 3-3. Fibre Content of Ingredients Used in Swine Diets.

Ingredient	Content (%)			
	Dietary Fibre	NDF	ADF	Crude Fibre
Barley	19	15	5	4
Corn	9	8	2	2
Peas	16	10	7	5
Soybean meal	24	15	9	8
Wheat	11	10	3	2

Adapted from: Graham 1988. Anim. Plant Sci. 1:76-80.

There are large differences in the values obtained by these measurements, although they all attempt to define the same component of feed ingredients - indigestible carbohydrate. Most Canadian feed testing laboratories report crude fibre, although acid detergent fibre and neutral detergent fibre measurements are gaining popularity.

The **ether extract (fat)** content of a feedstuff or diet is important because fat is rich in energy. All other factors being equal, the higher the fat content in a diet, the more digestible energy it will contain. Determining fat content provides some insight into how much energy is present. Fat content is estimated by determining the portion of the sample that is soluble in petroleum ether. This procedure is a standard one, but misses some important compounds, such as energy-rich phospholipids. In barley, for example, these phospholipids represent as much as 25% of the total fat in barley grain and contribute to its total energy.

Ether extract will also include such components as waxes and pigments, which are of little nutritional value. For this reason, the digestibility of the ether extract varies among grains as they vary in the relative proportion of phospholipids and waxes (Table 3-4).

What is the solution? Some nutritionists use different solvents in place of petroleum ether to extract the fat of feed grains thus developing a more complete analysis. Common alternative solvents include diethyl ether, and a 2:1 mixture of chloroform and methanol. Different solvents are used to answer different questions. As in most analyses, there is no complete test for all answers.

Table 3-4. Digestibility of Ether Extract of Common Feedstuffs.

Feedstuff	Percent Digestibility
Alfalfa meal	54
Barley	86
Corn	80
Soybean meal	80
Meat meal	93
Wheat	52
Wheat bran	58

Adapted from: Animal Feedstuff Table. 1991. Centraal Veevoederbureau, Runderweg 6, 8219 PK Lelystad, The Netherlands.

Amino acids supply energy only when they are not used for protein synthesis. Animals prefer to use amino acids to produce body protein. Amino acids supplied in excess of the animals' requirements for the synthesis of body protein or other nitrogenous compounds are degraded and used as an energy source. Since protein is a very expensive energy source, excess amino acids should not be added to a diet intentionally to help meet the pig's energy requirements. Much cheaper energy sources, such as carbohydrates, are preferred wherever applicable in a diet. In addition, some of the energy derived from amino acid degradation is required for the excretion (through urine) of nitrogenous compounds that are derived from amino acids. This requirement reduces the amount of available energy that can be derived from degraded amino acids.

Estimating Energy Contents in Feeds and Feed Ingredients

Evaluating the content of energy and other nutrients in feed ingredients is an important step in formulating diets for swine. Without knowing the amounts of nutrients supplied by individual ingredients, one cannot, with any degree of certainty, put together diets that will satisfy the pig's needs. Unfortunately, there is a considerable amount of variation in available energy contents between different samples of one feedstuff. For example, recent research at the Prairie Swine Centre demonstrated that DE content varied by as much as 10% between various samples of substandard wheat, with the poorest sample similar to that in regular barley. This demonstrates the use of average book values is not sufficient to estimate nutrients in specific samples of feed ingredients.

However, it is simply too expensive and time-consuming to evaluate the nutritional value of feedstuffs in feeding trials. There is thus a need for rapid, inexpensive, and practical tests for use in day-to-day diet formulation. Laboratory (chemical) evaluation can be of great assistance in meeting this need. World-wide research has attempted to develop chemical and alternative tests that give the true nutrient composition of ingredients and mixed diets, and accurately reflect the true feeding value.

An example of the progress made in this area is the use of near infra-red analyses (NIRA) to evaluate feed samples. Nutrient levels are estimated based on the feed sample's absorption of specific wavelengths of infra-red light. However, in order to properly calibrate NIRA equipment, large numbers of samples which enclose the entire range of samples to be tested and with known nutrient contents and availabilities are required. An alternative means to estimate available energy content in ingredients, as well as in complete feeds, is to chemically determine the content of various nutrients that supply energy (fat, protein, various fractions of carbohydrates such as starch sugars and specific fibres) as well as GE, and to use this information to predict its available energy content. For example, the following equation, developed by French researchers, can be used to estimate the DE content in complete pig diets.

DE (Kcal/kg of dry matter)* = 4168 - (9.1x Ash) + (1.9 x Crude Protein) + (3.9 x Ether Extract) - (3.6 x NDF)**

*The contents of the chemical constituents in the diet are expressed in grams per kg of dry matter.
**NDF - Neutral Detergent Fibre

In Chapter 4, various equations will be presented that can be used to predict DE content in specific samples of main feed ingredients.

A common misconception is that **bushel weight** is a good indicator of a cereal grain's nutrient quality, and DE content in particular. Premiums are sometimes paid for grains that exceed normal bushel weights, e.g., 23 kg (50 lb) barley or 26 kg (58 lb) corn. Unfortunately, like many of the factors used in the grading of grains, bushel weight is not a good indicator of feed value. Test weight can be affected by many factors, such as the shape and surface dimensions of individual kernels, which do not necessarily reflect nutrient content.

Research results show very clearly that energy concentration of grains does not fall in proportion with bushel weight. The energy content of typical 50 lb of barley is no different than that of 48 lb or even 46 lb of barley. In a recent study at Prairie Swine Centre, there was no relationship between DE content and bushel weight in wheat samples that varied in density between 53 and 63 lb/bushel. In the case of very low bushel weights, energy values do appear to fall; therefore, very low bushel weight grains should be used only in diets where energy concentration is not critical (gestating sows or growing pigs over 60 kg body weight) and even then, the concentration of other nutrients needs to be adjusted to reflect changing energy levels.

The rise in crude fibre coinciding with falling bushel weight is often put forward as an argument favouring the use of bushel weight as an indicator of grain quality. However, the rise in crude fibre, which is low in energy, appears to be offset by a similar rise in fat, which is high in energy (Table 3-5). Interestingly, bushel weight has been used as an indicator of flour yield, but even this relationship is suspect.

Table 3-5. Effect of Bushel Weight on Nutrient Content of Cereal Grains.

Bushel Weight kg (lb)	Crude Protein	Crude Fibre	Ether Extract
		- % -	
23 (51)	9.2	8.5	2.4
22 (49)	10.4	7.6	1.8
20 (45)	10.6	8.9	2.5
19 (42)	11.0	9.6	2.5

Table 3-6 offers guidelines for minimum bushel weights of cereal grains destined for use in swine diets.

Table 3-6. Minimum Recommended Bushel Weights for Grains Used in Swine Rations.

Grain	Bushel Weights (lb)	
	Standard	Minimum
Barley	48	43
Corn	56	50
Wheat	60	55

Guidelines for minimum bushel weights of grains used in swine diets. If grains below these standards are used, adjustments in energy content should be made.

Energy Requirements

A pig requires energy for almost all its body processes. Amino acids cannot be converted to muscle proteins and feed cannot be digested or wastes eliminated without energy. Body temperature cannot be maintained , gestating sows cannot produce a fetus, nor can nursing sows produce milk without energy. Clearly, energy is fundamental to all life.

A pig's requirement for energy will be determined by a number of factors. The pig's size is important because energy needed for maintenance is directly related to body size. It 'costs' more in terms of energy to maintain a 250 kg sow than a 180 kg sow. The pig's productive state is also an important factor. A lactating sow requires more energy than a gestating sow since she is producing large quantities of milk. A pig that is gaining weight requires more energy than one that is not growing. As described previously, the environment in which a pig is housed is also critical. In cold temperatures or wet, drafty conditions, energy required to maintain body temperature rises. If pigs can huddle with each other, their energy requirements in cold weather are lower than if they are penned individually.

The amount of energy required in feed is determined by considering both quantity of feed consumed per day and amount of energy required per day. This principle is important. For example, a man working at a job that involves considerable physical exertion has a high energy requirement per day. In theory, this requirement could be met by eating an enormous quantity of lettuce or other bulky, low energy, foods. In practice, this approach will not work because the man simply cannot physically consume enough lettuce to meet his energy needs. If he is given a diet of meat and potatoes, i.e., high energy foods, he can easily consume enough food to meet his daily energy needs. The message here is that gut capacity plays an important role in formulating diets.

The same principle applies to pigs. If the concentration of energy in the diet is too low, the pig may be unable to consume sufficient amounts to meet its energy needs. A gestating sow is fed less than her appetite demands to prevent excess weight gain. Her stomach capacity is more than sufficient to meet her energy needs with most practical diets. Conversely, the lactating sow has a very high energy requirement to support milk production and maintain her body condition in preparation for the subsequent breeding period. If she is fed a low energy diet, she will be unable to consume sufficient energy per day, will lose body weight, and produce less than her maximum potential of milk.

Pigs up to about a 60 kg body weight (130 lb) being fed traditional ingredients may be in danger of growth retardation because their gut capacity is insufficient to accommodate the energy required for them to grow quickly. In pigs with extremely high (lean) growth potential, such as boars, energy intake may limit growth up to higher body weights. However, in most finishing pigs of 60 kg or heavier body weight, gut capacity no longer places a limit on growth, assuming normal ingredients are used. Because of limitations in gut capacity relative to energy needs, diets with a high concentration of energy should be fed to younger pigs and lactating sows. These are called high nutrient density diets. Lower energy grains, such as oats, are too low in energy to support maximum growth rate.

Refer to the specific chapters on feeding various classes of pigs for further information on energy requirements. Any general requirement must consider many variables, such as environmental temperature, desired performance, body size, and some score of genetic capacity.

Amino Acids

Amino acids are the building blocks of protein, meaning that all proteins are made up of individual amino acids linked together like beads in a necklace. In nature, there are about 22 amino acids that can link together to form proteins. Pigs can produce some of them from other substances; but they cannot synthesize 10 amino acids so they must be provided by the diet. These 10 amino acids are called the 'essential amino acids' (Table 3-1). If they are not present in the diet, or are present in insufficient quantities relative to need, the animal will be unable to grow properly.

In addition to the 10 essential amino acids, there are two so-called semi-essential amino acids, cystine and tyrosine, that can be synthesized only from essential amino acids, methionine and phenylalanine, respectively. The term 'total sulphur amino acids' (T.S.A.A.), refers to the sum of methionine plus cystine. Pigs require T.S.A.A. in addition to the requirements for methionine. This requirement indicates the importance of monitoring both methionine and cystine levels in swine feeds. At least 50-55% of the total T.S.A.A. requirements must be supplied by methionine. In the same manner, phenylalanine must supply approximately 55% of the animals' requirements for phenylalanine plus tyrosine. The sum of phenylalanine and tyrosine is also referred to as "total aromatic amino acids". Phenylalanine and total aromatic amino acids are rarely deficient in practical diets. Consequently, under practical conditions, tyrosine is much less important than cystine.

When the pig eats protein as part of its diet, the intestinal tract breaks down protein into individual amino acids. These amino acids are then transported into the blood and carried to various tissues where they are used for a variety of purposes. The most obvious function is to form muscle protein. However, a host of other proteins in cells are just as important since they support a wide range of essential body functions. Enzymes, such as those that help to digest food in the gut, or those that help ensure that overall metabolism in tissues flows smoothly, are proteins. There are also carrier proteins that transport nutrients from one side of the cell wall to the other. Haemoglobin in the blood is a protein; it transports oxygen from the lungs to the tissues to support cell metabolism. The blood also contains many other proteins, such as those which transport certain vitamins or minerals. Milk contains proteins to nourish newborn piglets. Immunoglobulins circulating in the blood protect animals against specific forms of disease.

Although protein synthesis is important, individual amino acids also perform other functions. For example, tryptophan is converted into serotonin, a chemical called a neurotransmitter, that is involved in the transmission of signals by the nervous system. It is this function that has prompted some people to recommend tryptophan supplements as a calming influence in the diet. Tryptophan can also be converted to the vitamin niacin, thereby reducing, but not eliminating, the need for niacin in the diet.

Estimating Protein and Amino Acid Contents in Feeds and Feed Ingredients

The crude protein content is an **estimate** of the amount of protein present in a feed ingredient or mixed diet. Since amino acid analysis is very expensive and time-consuming, crude protein has been adopted as a more practical indicator of feed value. Direct analysis for amino acids will become a much more common procedure in the future.

Crude protein is usually measured using the Kjeldahl method. According to this very old, but simple and accurate method, feed is digested in acid and the quantity of total nitrogen in the sample is determined. The total nitrogen value is then multiplied by the 'Kjeldahl' factor of 6.25 to generate the crude protein value.

The crude protein content of feedstuffs must be interpreted with great care for three main reasons: The true Kjeldahl factor varies from ingredient to ingredient; not all of the nitrogen in a feed sample is associated with true protein; and total protein is a very rough estimate of the amino acids present.

The first point: The true Kjeldahl factor varies from ingredient to ingredient. The Kjeldahl factor of 6.25 assumes that the protein in the sample contains 16.0% nitrogen. This assumption is not necessarily true. As mentioned previously, protein consists of individual amino acids. The proportion of nitrogen in each amino acid varies from 7.7 to 32.2 (Table 3-7) so the actual amount of nitrogen present in a protein will depend on the relative proportions of each amino acid in the protein. As the proportion of amino acids change, so will the average proportion of nitrogen in the final protein. Corn protein contains 16.0% nitrogen while the protein in wheat or barley contains about 17.2% nitrogen. Therefore, the correct factor for wheat and barley is 5.83. Using 6.25 for these two cereals will overestimate protein content by about 7%.

However, the standard Kjeldahl factor is necessary because the proper nitrogen correction value is not always known. For example, if a pork producer submits a mixed feed for analysis, what value should be used to adjust nitrogen to crude protein? A universally accepted standard is required and 6.25 has become that accepted standard.

Table 3-7. Nitrogen Content of Amino Acids.

Amino Acid	% Nitrogen
Methionine	9.4
Cystine	11.6
Lysine	19.2
Tryptophan	13.7
Phenylalanine	8.5
Leucine	10.7
Isoleucine	10.7
Threonine	11.8
Valine	12.0
Histidine	27.1
Arginine	32.2
Glycine	18.7
Asparagine	21.2
Aspartic Acid	10.5
Serine	13.3
Glutamine	19.2
Glutamic Acid	9.5
Proline	12.2
Alanine	15.7
Tyrosine	7.7

The second point: Not all of the nitrogen in a feed sample is associated with true protein. Some of the nitrogen in feed ingredients is in the form of non-protein nitrogen. There are compounds that contain nitrogen but are not protein. Including them in the crude protein calculation will overestimate the quality of the ingredient. The information in Table 3-8 summarizes these two points. It provides the 'corrected' Kjeldahl factor, two crude protein values (one obtained from the standard Kjeldahl factor, one from the corrected factor) and the corrected crude protein value adjusted for non-protein nitrogen.

The third point: Total protein is a very rough estimate of the amino acids present. Total protein, even adjusted for non-protein nitrogen and using the corrected Kjeldahl factor, is not a perfect indicator of amino acid content. For example, in cereal grains lysine contributes to approximately 4% of corrected protein, while in soybean meal this value exceeds 7.5%. As lysine is generally the first limiting amino acid in pig diets, this means that protein in soybean meal is close to two times more valuable than cereal grains in meeting the pig's amino acid requirements.

Table 3-8. Protein Estimation Adjusted for Corrected Nitrogen Factors and Non-protein Nitrogen Content.

Feedstuff	Corrected Factor	Crude Protein (CP) N x 6.25	Crude Protein (CP) N x Corrected Factor	Non-protein Nitrogen (% of CP)	Corrected Protein
		(%)			
Barley	5.83	10.6	9.89	18.2	8.09
Canola Meal	5.53	37.7	33.36	-	-
Corn	6.25	8.5	8.50	22.2	6.61
Milk, Fresh	6.38	3.3	3.40	11.1	3.01
Oats	5.83	10.8	9.79	25.0	7.34
SBM	5.71	47.5	43.40	18.4	35.41
Wheat	5.83	13.5	12.59	16.7	10.49
Wheat Bran	6.31	15.5	15.65	20.0	12.52

Source: unknown.

We do not suggest eliminating the crude protein measure since it is a simple, rapid, and inexpensive test which is required to provide an estimate of protein quality. However, failure to consider the underlying principles could lead to serious errors in diet formulation. For greatest precision, crude protein should be used in conjunction with estimates of amino acid composition.

The pig requires amino acids that make up protein. It is possible to analyse ingredients for their amino acid content but it is an expensive procedure that costs as much as $150 per sample. How then can diets be formulated on the basis of amino acids, when such analyses are so expensive?

Nutritionists have a number of options open to them. Most use book values for amino acids. These values will be validated from time to time by amino acid analyses to confirm their accuracy. Nutritionists also use 'prediction' equations to adjust individual amino acid content based on changes in nitrogen content. Prediction equations are becoming more common and, as further studies are completed, will improve in accuracy. At this time, however, they must be used with caution.

> The following regression equations can be used to estimate the amino acid content of common grains and protein sources.
>
> (Courtesy: Degussa Corporation)
> The ingredients tested to obtain these equations were not necessarily all Canadian.

Barley (Canadian, N=59 samples)

% Lysine = % CP x 0.0269 + 0.097; r = 0.91
% Methionine = % CP x 0.0154 + 0.027; r = 0.95
% T.S.A.A. = % CP x 0.0304 + 0.118; r = 0.92
% Threonine = % CP x 0.0318 + 0.029; r = 0.96
% Tryptophan = % CP x 0.0076 + 0.051; r = 0.76

Wheat (N=148 samples)

% Lysine = % CP x 0.0194 + 0.094; r = 0.82
% Methionine = % CP x 0.0163 + 0.009; r = 0.87
% T.S.A.A. = % CP x 0.0343 + 0.042; r = 0.90
% Threonine = % CP x 0.0264 + 0.026; r = 0.94
% Tryptophan = % CP x 0.0087 + 0.037; r = 0.79

Corn (N=153 samples)

% Lysine = % CP x 0.0224 + 0.057; r =0.64
% Methionine = % CP x 0.0192 + 0.015; r = 0.62
% T.S.A.A. = % CP x 0.0345 + 0.073; r = 0.56
% Threonine = % CP x 0.0336 + 0.014; r = 0.84
% Tryptophan = % CP x 0.0026 + 0.041; r = 0.41

Soybean Meal (N=277 samples)

% Lysine = % CP x 0.0665 + 0.252; r = 0.70
% Methionine = % CP x 0.011 + 0.127; r = 0.44
% T.S.A.A. = % CP x 0.0255 + 0.157; r = 0.52
% Threonine = % CP x 0.0344 + 0.203; r = 0.65
% Tryptophan = % CP x 0.0144 + 0.041; r = 0.62

Canola Meal (N=57 samples)

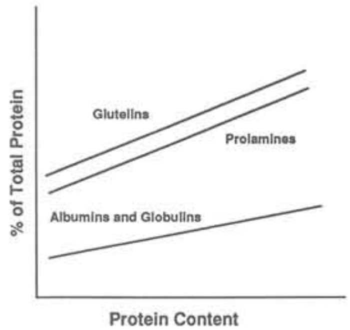
% Lysine = % CP x 0.0231 + 1.133; r =0.29
% Methionine = % CP x 0.0157 + 0.177; r = 0.67
% T.S.A.A. = % CP x 0.0419 + 0.140; r = 0.60
% Threonine = % CP x 0.0377 + 0.250; r = 0.74
% Tryptophan = % CP x 0.0105 + 0.510; r = 0.51

Triticale (N=26 samples)

% Lysine = % CP x 0.0209 + 0.140; r = 0.88
% Methionine = % CP x 0.0147 + 0.024; r = 0.90
% T.S.A.A. = % CP x 0.0332 + 0.069; r = 0.93
% Threonine = % CP x 0.0264 + 0.047; r = 0.95

These equations can thus be used to adjust estimated amino acid levels based on the analysed protein content in the various ingredients. The crude protein content of ingredients may vary with cropping conditions, such as heavy fertilization or a dry growing season and methods of processing. The equations indicate that the limiting amino acid concentration does not increase proportionally with the rise in crude protein. This is because the proportions of the cereal proteins, albumens, globulins, prolamines and glutelins, vary with protein content. For example, the albumens and globulins are well balanced proteins, rich in both lysine and tryptophan. Prolamine protein is a very poor source of lysine and tryptophan (Table 3-9).

As crude protein content rises, the prolamine protein tends to increase at a faster rate than albumen and globulin forms (Figure 3-3). Consequently, the essential amino acid content of higher protein grain reflects more the amino acid profile of the prolamine protein and less the profile of nutritionally superior albumens and globulins. Thus, lysine decreases as a proportion of the total. Oats are an exception to this rule, since the prolamine protein proportion in oats is low. The effect of differing nitrogen contents of wheat and oats on lysine content is shown in Table 3-10.



Adapted from Hosenay, R.C. 1986. Principles of Cereal Science and Technology, American Association of Cereal Chemists, Inc.

Figure 3-3. Relationship of Protein Content to Protein Type in Cereal Grains.

Amino Acid Availabilities in Feed Ingredients

In addition to the total amino acid content in feed ingredients, the availability of these amino acids should also be considered in practical feed formulation. Over the last decade, a considerable amount of research has been conducted that demonstrates large differences in amino acid availabilities between various feedstuffs. For example, the availability of lysine in canola meal is lower than that in soybean meal. If these differences are overlooked in a feed formulation

Table 3-10. Effect of Increasing Total Nitrogen (Crude Protein) on the Lysine Content of Wheat and Oats.

Crude Protein in Grain (%)	Proportion of Lysine in Total Protein (Percent of Total Amino Acids)	
	Wheat	Oats
9.4	3.3	4.4
12.5	3.1	4.2
15.6	2.8	4.1
18.8	2.6	4.0
21.9	2.4	3.8

Adapted from Eppendorfer, 1978. J. Sci. Food Agric. 29:995-1001.

(i.e. diets are formulated based on total rather than available amino acid levels) then animal performance will likely be reduced if soybean meal is replaced by canola meal. However, research at various institutions, including the Prairie Swine Centre, has demonstrated that when diets are formulated based on available amino acid levels in canola meal and soybean meal, animal performance can be maintained at high levels even if large quantities of canola meal are included in the diet.

Differences in availabilities between feedstuffs can be attributed to various factors. These factors include fibre levels, levels of anti-nutritional factors that interfere with nutrient digestion and utilization, protein quality, and heat damage. For example, raw soybeans contain anti-nutritional factors called trypsin inhibitors, which reduce the trypsins' effectiveness (trypsins are digestive enzymes produced

Table 3-9. Amino Acid Profile of Various Protein Fractions in Corn (g/100g of protein).

Amino Acid	Albumins and Globulins	Prolamines		Glutelins
		Zein A	Zein B	
Arginine	7.35	2.16	3.46	4.49
Isoleucine	4.25	3.53	2.23	3.97
Lysine	4.18	0.46	0.57	4.38
Phenylalanine	3.57	6.11	2.56	5.31
Leucine	6.50	17.49	10.23	12.09
Methionine	1.72	0.94	1.63	2.86

Adapted from: Robutti, J.L., et al., 1974.

by pigs). When soybeans are processed (oil extraction or roasting), these trypsin inhibitors will be inactivated.

Amino acid availabilities are routinely estimated from apparent ileal digestibilities, i.e., the disappearance (absorption) of amino acids from the digestive tract prior to the end of the small intestine (terminal ileum). Ileal digestibilities are a better reflection of amino acid availabilities than digestibilities measured over the entire digestive tract because essential amino acids that enter the large intestine, or cecum, may be altered by resident bacteria. The bacteria may break down some of these amino acids, convert them to other amino acids, or even manufacture new amino acids from ammonia, thus contributing to an inaccurate digestibility measurement. Essential amino acids that are digested by bacteria present in the pig's large intestine and cecum are not available to the animal. Therefore, to measure the net amounts of amino acids extracted from the diet, digesta is collected before it enters the large intestine. Measuring amino acids excreted in the feces will not reflect unabsorbed amino acids, but rather unabsorbed amino acids after possible alteration by the bacteria. Many nutritionists now formulate diets using ileal digestible amino acids rather than total amino acids in a feedstuff.

Table 3-11 summarizes the estimated apparent ileal digestibility of amino acids from common feed ingredients. The word 'apparent' refers to the fact that the values are not adjusted for what are called endogenous (internally produced) secretions.

Amino acids consumed in the diet are not the only amino acids entering the small intestine. Endogenous secretions, which include sloughed off intestinal cells, digestive enzymes, and possibly hormones, are added by the stomach, the salivary glands, and the small intestine. This process was described in chapter 2. If these endogenous secretions were constant, apparent digestibilities could be easily corrected to true digestibilities. However, that is not the case, and many factors appear to influence the quantity of endogenous secretions in the gut. An important observation is that endogenous gut protein losses appear to increase as the protein level in the diet is raised. Because separating endogenous secretions from those of dietary origin is difficult, estimating true amino acid digestibilities in feedstuffs for swine is not yet possible.

There is, however, a concern about apparent amino acid digestibilities in pig feed ingredients related to these endogenous secretions. More specifically, the apparent amino acid digestibilities in a mixture of ingredients many not be the same as that calculated from the inclusion level of the various ingredients in the diet and their apparent digestible amino acid contents. This may cause errors in feed formulation. This concern can be attributed to the effects of dietary amino acid levels (or inclusion levels of the protein source in the test diet) on observed apparent amino acid digestibilities (Figure 3-4a). For example, the apparent amino acid digestibilities in cereal grains, and corn in particular, are generally lower than in protein sources such as soybean meal. This is because amino acid digestibilities in cereal grains are determined at lower levels of amino acids in the test diet. This corresponds to low apparent amino acid digestibilities (Figure 3 - 4a).

Apparent amino acid degestibilities in protein sources, such as soybean meal and canola meal, are determined at higher amino acid levels in the test diet, corresponding to higher apparent amino acid digestibilities (Figure 3-4a). If corrections are made for the minimum endogenous gut amino acid losses, then the corrected "true" amino acid digestibilities are generally independent of the dietary amino acid level (Figure 3 - 4a). Minimum gut amino acid losses can be derived from feeding protein free diets or from regression to zero protein intake when various diets are fed with varying protein levels (Figure 3-4b). However, it should be stressed that the actual endogenous gut amino acid losses are higher than the minimum losses and they are affected by various dietary and animal factors. This implies that these corrected "true" digestibilities are merely a means to improve the precision of diet formulation; they are not an accurate reflection of the actual true digestibility of amino acids in feedstuffs.

Table 3-11. Average Apparent Availability of Amino Acids (%) in Common Ingredients.

Ingredient	Isoleucine	Lysine	Methionine	Threonine	Tryptophan	Valine	Cystine
Alfalfa Meal	55	47	62	47	54	52	22
Barley	74	68	79	64	68	71	72
Blood Meal	66	84	78	81	80	85	74
Canola Meal	72	74	78	68	64	78	77
Corn	78	65	86	68	64	78	76
Fish Meal (high quality)	85	86	87	80	76	83	65
Meat & Bone Meal	71	70	77	66	55	72	54
Oat Groats	83	79	83	75	80	83	76
Peas	78	83	77	69	67	71	60
SBM (44%)	82	84	85	76	80	79	74
SBM (47%)	83	85	85	78	80	81	78
Sunflower Meal	78	74	87	72	77	75	73
Triticale	80	73	83	64	70	78	82
Wheat (HRS)	83	72	84	71	79	79	81
Whey	88	81	88	82	82	87	90

Derived from: Centraal Veevoeder Bureau (1994 Table of Feeding Values of Animal Feed Ingredients); Heartland Lysine (1994 Swine and Poultry Digestibility Tables); BioKyowa (1991 Digestible Amino Acids and Digestible Amino Acids for Swine, BioKyowa Technical Review 2); Rhone Poulenc (1990, first version, Nutrition Guide); Degussa (Ileal Digestible Amino Acids in Feedstuffs for Pigs).

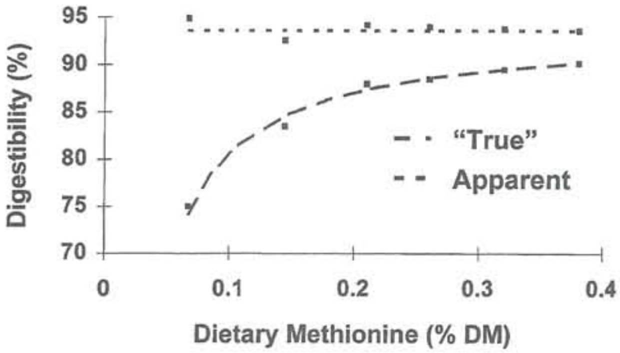


Figure 3-4a.

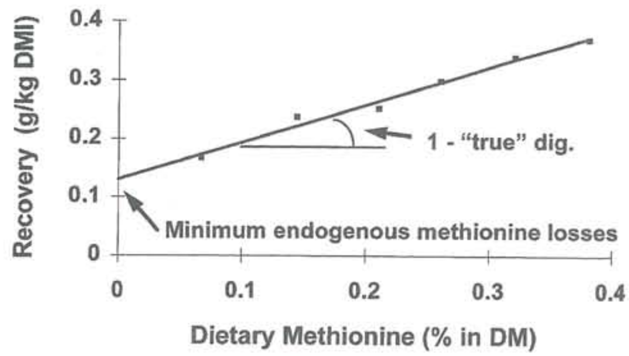


Figure 3-4b.

Figure 3-4. Relationship between Amino Acid Level in Diet and Observed Apparent and Calculated[1] "True" Ileal Amino Acid Digestibilities (Figure 3-4a), and the Relationship between Amino Acid Level in Diet and Observed Recovery at Distal Ileum (Total Endogenous and Non-digested Dietary Amino Acids)(Figure 3-4b).

[1]According to a review of the literature, it can be estimated that the minimum endogenous gut amino acid losses (AAend; g/kg dry matter intake) are 0.38 - lysine, 0.10 - methionine, 0.31 - methionine plus cystine, 0.51 - threonine, 0.18 - tryptophan, and 0.24 - isoleucine. The "true" digestibility (TD, %) can be calculated from observed apparent digestibilities (AD, %) and the amino acid level in the test diet (AAd, g/kg dry matter) as follows: TD = 100 x (1-[AAd-{AAd x AD/100} - AAend]/AAd). Note that the slope in the right hand graph represents the true digestibility.

Derived from Fan, M. R. 1994. Methodological considerations for the determination of amino acid digestibility in pigs. PhD. Thesis. University of Alberta.

If diets are formulated based on 'true' rather than apparent ileal digestible amino acid contents in feed ingredients, then adjustments may have to be made to the requirements as well. Requirements expressed as apparent digestibilities (g/kg of diet) can be converted to those expressed as 'true' digestibilities, simply by adding the minimum gut amino acid losses (g/kg of diet; g/kg of dry matter x dry matter content of the diet/100).

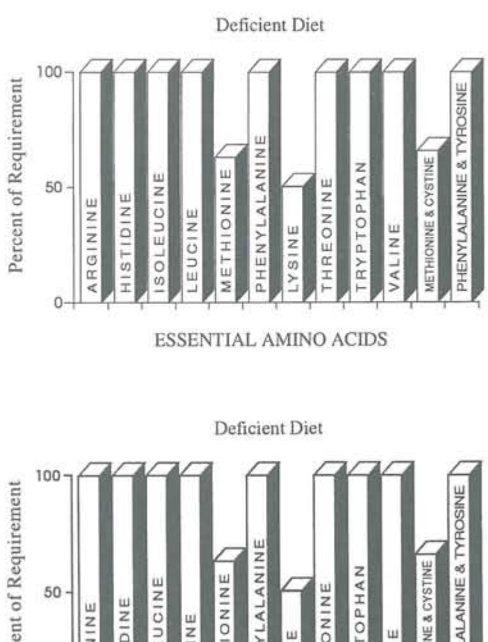
Unfortunately (apparent, or true, ileal) digestibilities do not always provide a good estimate of amino acid availability. The amino acids in some ingredients are digestible but unavailable because they are absorbed in a form which renders them useless to the animal. These amino acids are excreted, mostly in the urine. This occurrence is a concern especially for heat treated ingredients of animal origin — milk products, blood meal, meat meal, fish meal — but also applies to some ingredients of plant origin.

One of the unfortunate features of reduced availability of amino acids due to heating is that lysine is the amino acid most affected. Lysine can interact with sugars in a chemical reaction called 'carmelization'. This reaction is stimulated by heat in the presence of moisture, the exact conditions present in the drying process. Carmelization, as its name suggests, is associated with a colour change in the grain or protein. Thus, darkened grains or protein supplements tend to be down-graded for livestock due to concerns about carmelization and associated changes in lysine availability. At present, there is no assay available that will allow us to routinely evaluate this chemical (un)availability.

Amino Acid Requirements

Clearly, dietary protein is very critical to the pig. None of the body processes described above could occur without the necessary proteins being present. Consequently, inadequate amino acid intake from the diet resulting in impaired protein synthesis has a profound effect on a pig's health and productivity. That amino acids present in the diet are balanced according to the pig's need is very important. If all other amino acids are present in quantities well above requirement, but lysine is missing or inadequate, the pig will still be unable to grow to its full potential because it must have **all** amino acids present in adequate quantities. Each individual protein is created by a specific sequence of amino acids; the lack of any single amino acid can prevent formation of the total protein.

The importance of a proper balance of amino acids is illustrated in Figure 3-5. In the adequate diet, all amino acids are present at 100% of requirement. Thus, when the body requires amino acids for protein synthesis, each will be present in sufficient quantity. In the inadequate diet, both lysine and methionine are present at levels well below requirement. If lysine is present at 50% of the requirement, it will place this upper limit on the rate of protein synthesis. Not only will body functions be impaired, but other amino acids supplied in adequate quantity will be wasted.



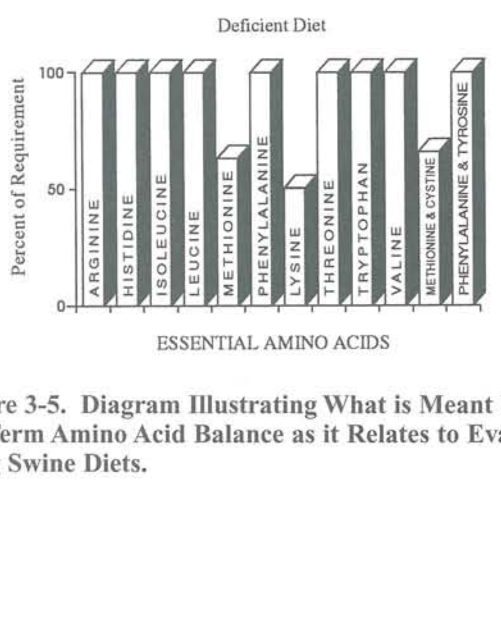


Figure 3-5. Diagram Illustrating What is Meant by the Term Amino Acid Balance as it Relates to Evaluating Swine Diets.

The explanation above brings up the concept of the 'first limiting' amino acid. In Figure 3-5, lysine would be the first limiting amino acid in the deficient diet because the amount present is lower, relative to requirement, than any other amino acid. Methionine would be considered second limiting. There are no third limiting amino acids in this example. Lysine is the amino acid discussed most often because in practical diets for swine, it is the one most likely to be first limiting. Thus, nutritionists pay particular attention to lysine. Remember, however, that while adding extra lysine to a deficient diet will be beneficial, you must also consider the supply of other limiting amino acids if the diet is to be fully balanced.

The balance in which amino acids are required by pigs can be determined in a number of ways. Until recently, the most common approach was to study individual amino acids and determine the requirement of each one in terms of maximum growth rate or carcass quality. A second approach, gaining in popularity, is to relate the requirement for all amino acids to one reference amino acid, often lysine. This approach emphasizes the concept of amino acid balance and integrates the requirement for all 10 essential and two semi-essential amino acids. For example, the requirement for lysine is defined in absolute terms (e.g., 1.3% in a starter diet). The requirement for the other amino acids is then established relative to lysine.

Table 3-12 provides an estimate for the optimum amino acid balance, also referred to as the ideal dietary protein. Lysine is set at 100 and all other amino acids are defined relative to 100. For example, the amount of tryptophan in a diet should be about 19% of lysine, while threonine should be 65% of lysine. Thus, in a diet containing 0.85% lysine, there should be at least 0.16% tryptophan and 0.55% threonine. Remember that the balance in which amino acids are required by pigs will vary somewhat with body weight, (lean) growth rate, level of milk production, and diet composition. For example, as pigs grow heavier relatively more protein is required for body maintenance functions. Because proteins required for body maintenance functions contain large quantities of threonine and T.S.A.A. relative to lysine, requirements for threonine and T.S.A.A., expressed as a proportion of lysine, will increase as pigs grow heavier. In a similar fashion, requirements for threonine and T.S.A.A., relative to lysine, will reduce as lean growth rates in pigs continue to increase. The concept of ideal protein, the optimum balance in which amino acids are required by pigs, has proven very useful in practical swine diet formulation. This concept allows for a rapid estimation of requirements for essential and semi-essential amino acids once the requirements for one amino acid have been established. Determining the optimum amino acid balance for different groups of pigs under varying conditions remains an important area in swine nutrition research. Refer to the specific chapters on feeding various classes of swine for further information on amino acid requirements and optimum dietary amino acid balances.

Table 3-12. Suggested Optimum Amino Acid Balance in Protein (Ideal Protein) for Swine.

Amino acid	Suggested balance
Lysine	100
Threonine	60-70
Methionine	30
Methionine plus cystine (T.S.A.A.)	56-64
Tryptophan	18-20
Isoleucine	60
Leucine	100
Phenylalanine	60
Phenylalanine + tyrosine	100
Valine	70
Histidine	30
Arginine	45

Minerals

Minerals are an important constituent of the pig's diet. As a group, they perform far more functions in the body than they are normally given credit for. We tend to associate minerals, such as calcium and phosphorus, with the hard structures of the body because of their involvement with bones and teeth. However, minerals have other important functions to fulfill if the pig is to perform well. Many enzymes will not function unless certain minerals are present. Muscles could not contract and nerves could not send signals in the absence of minerals.

Minerals can be assayed directly in feedstuffs with great accuracy and precision. Samples are first ashed using very high temperatures (550°C) or strong acids to remove all but the mineral content. This residual material is then dissolved in weak acid and assayed by various methods.

Minerals can be divided into two types: macrominerals and microminerals (Table 3-13). They are differentiated solely by the relative amounts present in the diet. Macrominerals are present in greater concentration and are therefore measured in terms of percent or grams per kilogram (1 g/kg equals 0.1%). Microminerals are present in much smaller quantities and are measured in terms of parts per million or milligrams per kilogram (1 ppm equals 1 mg/kg). Thus, the concentration of microminerals in the diet is about one-tenth to one-ten thousandth that of the macrominerals. To put ppm and percent in perspective: 1 ppm is 1 second out of 11.5 days; 1 percent is approximately one second out of 1.5 minutes.

The quantity of each mineral present in a pig's body reflects, in a general way, the amount required in the diet. Table 3-13 shows the approximate concentration of minerals in the animal body. Note that calcium and phosphorus are present in by far the highest concentration, while minerals such as selenium and chromium can be found only in trace amounts. Calcium and phosphorus are involved in the skeleton and are thus present in large quantities, while selenium supports the activity of certain enzymes, a role which requires only trace amounts. Importance should not be equated with quantity; a deficiency of a micromineral can be just as serious as that of a macromineral.

Table 3-13. Approximate Mineral Composition of the Animal Body.

Macrominerals Element	%	Microminerals Element	ppm
Calcium	1.50	Iron	20-80
Phosphorus	1.00	Zinc	10-50
Potassium	0.20	Copper	1-5
Sodium	0.16	Manganese	0.20-0.50
Chlorine	0.11	Iodine	0.3-0.6
Sulphur	0.15	Molybdenum	1-4
		Selenium	1.7
		Chromium	0.08

Adapted from: McDonald, et al. 1973.

Macrominerals

Calcium

Most of the body's calcium is present in bones. Bone ash contains about 36% calcium and 17% phosphorus. Calcium deficiencies lead to leg weakness, lameness, and in extreme cases, bone fractures. Bone is a strong and dynamic tissue. It is dynamic in that calcium and phosphorus in the bone are constantly being exchanged for calcium and phosphorus in the blood. Since bone is rigid and strong, many people think bones are not alive. That, clearly, is not true!

The fact that so much of the body calcium is present in bone often leads people to ignore its other very important functions. For example, calcium is required for blood to clot and for muscle and nerve function. Calcium helps regulate the acid-base status of blood and is involved in regulating cell division and hormone secretion. Because of its important role in muscle contraction, calcium deficiency can lead to cramping and even tetany.

Basal ingredients in most diets are poor sources of calcium. For example, cereal grains contain less than 0.05% calcium and vegetable protein supplements also contain only small quantities. Meat meal is an excellent source of both calcium and phosphorus but due to its variability, must be formulated into the diet with caution. Fortunately, an inexpensive source of calcium, limestone (38% calcium), is available for diets.

Although limestone is not expensive, supplementing large quantities of calcium 'costs' a considerable amount in terms of the total diet because limestone dilutes all other nutrients. Although calcium is added to the diet at least expense by using limestone, limestone contains no energy or protein, so adding it in place of barley or corn or any other basal grain will reduce the diet's energy and amino acid content unless other adjustments are made. To provide a rough estimate of the true cost of additional calcium in a diet, multiply the cost of limestone required to meet the new levels by approximately 2 or 3. This equation accounts for the cost of overcoming nutrient dilution by limestone as well as the cost of adding the calcium itself.

Take care to avoid too much dietary calcium because it can lead to depressed feed intake. This situation appears a greater problem in starter diets and lactation rations than at any other time because in both cases, feed intake is a major concern, and these diets tend to be formulated to contain high levels of calcium to meet the pig's nutrient requirements. Although the exact limit for calcium has not been defined, levels in excess of 1.25% should be avoided. This level poses no hardship, since no diet needs to contain more than about 1.20% calcium, and most diets are quite adequate at 0.90% or lower.

Phosphorus

Phosphorus, along with calcium, is a major bone component. More phosphorus, however, is present outside the bones than is the case with calcium. While about 99% of body calcium is present in bones and teeth, only about 80-85% of the phosphorus is present in these tissues. The metabolism of carbohydrates, fats, and amino acids all require phosphorus. Phosphorus performs numerous other functions, including being a major part of the 'energy currency' in the body. This chapter has already discussed how the body is able to break down food materials and convert it into energy forms. Certain compounds in the body which contain phosphorus (ATP, creatine phosphate) trap this energy and transport it to the site of use in the cell. In the same way that money allows us to earn cash in one location at one time and spend it at a different location at a later time, phosphorus allows the body to generate energy in one location for later use in a different part of the cell. Although none of this activity requires large amounts, phosphorus is nonetheless important to keep the body functioning properly.

A major concern with respect to dietary phosphorus levels is the proportion the pig actually utilizes. A part of the phosphorus supplied by cereal grains and vegetable proteins is bound to phytate and is much less available than in other forms. Table 3-14 shows the amount of total phosphorus present in common ingredients and an estimate of phosphorus availability.

Table 3-14. Total Phosphorus Content and Phosphorus Availability of Some Common Ingredients.

Ingredient	Total Phosphorus (%)	Phosphorus Bio-availability (%)
Corn, dry	0.25	15
Corn, high moisture	0.25	49
Barley	0.29	31
Wheat	0.34	50
Oats	0.31	30
SBM, 47%	0.60	25
Canola meal	1.07	21
Peas	1.01	47
Wheat middlings	0.95	45
Wheat bran	1.10	35
Meat and bone meal	4.75	68

Derived from NRC, 1988 and table of feeding values of Animal Feed Ingredients (Centraal Veevoeder Bureau) The Netherlands.

Whereas phytate is an undesired component of swine diets, it plays a very important role for growing plants that need it to store phosphorus for later use. Late application of fertilizer may increase total phosphorus in the seed but much of the additional mineral is in the form of phytate and less available to the pig when it eats the plant.

Phosphorus is a much more expensive ingredient than calcium, so maximizing utilization should be a priority. Presently, the addition of 0.1% additional calcium costs about forty cents per tonne while 0.1% additional phosphorus costs two dollars. As with calcium, part of this cost is associated with the cost of the phosphorus itself and part is overcoming the diluting effect of the added phosphorus source. Commonly used sources of supplemental phosphate are shown in Table 3-15.

Table 3-15. Feed Grade Phosphate Sources.

Source	Phosphorus	Calcium (%)	Sodium
Bone meal	12.0	24.0	-
Defluorinated phosphate	18.0	31.0	4.0
Diammonium phosphate	20.0	trace	-
Dicalcium phosphate	18.0	21.0	-
Monocalcium phosphate	22.0	16.0	-

Note: Actual nutrient composition may vary depending on the supplier. Nutrient composition should be confirmed by chemical analysis.

Given the low availability of phosphorus in most swine feed ingredients, the cost of phosphorus, and the contribution of phosphorus excreted with swine manure to environmental pollution in areas with extensive swine operations, there is much interest in enhancing the efficiency with which dietary phosphorus is utilized by pigs. A means to accomplish this is to add enzymes, called phytases, to the pig's diet. Various studies have shown that these enzymes enhance the availability of phytate phosphorus in pig feed ingredients. This reduces the need for inorganic phosphorus in pig diets. Concerns with the use of these phytases include cost and product stability. Phytases are generally unstable at higher temperatures which is a concern when feeds are pelleted. It should be noted that some ingredients such as wheat and triticale contain some endogenous phytases.

The ratio of calcium to phosphorus, and more accurately, available phosphorus, in the diet should also be considered. Dietary calcium to phosphorus levels of 3:1 and 1.25:1 for available and total phosphorus, respectively, are thought to optimize calcium and phosphorus utilization. The importance of the ratio appears to be greater if calcium is present at or slightly above requirement. In practical diets the ratio of calcium to available phosphorus in the diet should be maintained at 2.7 to 3.4. This corresponds with calcium to total phosphorus rations of approximately 1.1 to 1.5. If the diet contains plenty of calcium and phosphorus, the ratio becomes much less important. A deficiency in vitamin D also impairs the utilization of calcium in the diet.

Sodium

Sodium, together with potassium and chloride, is required by the body to maintain proper water balance and to help generate the electrical charges needed by muscles and nerve tissue to function normally. Sodium is particularly important in the body's many transport processes. Absorption of amino acids, sugars, many minerals, and water from the gut could not occur without sodium.

Sodium is often considered to be 'salt' since table salt is actually sodium chloride and contains about 39% sodium. This explanation may be a convenient one but is not physiologically or even nutritionally appropriate. Sodium and chloride are quite distinct chemicals and should be considered as distinct entities. They are required independently in a pig's diet.

The most obvious symptom of sodium deficiency is a depressed appetite. Excess sodium can result in diarrhea. Since many diseases also cause diarrhea, observing only this symptom is not a very effective way to diagnose salt excesses in the diet! Although pigs may become loose if excess salt is present in the feed, they can tolerate very high levels without loss of performance **if** they have access to plenty of clean water. If access to water is restricted, pigs receiving excess salt in their diet can die. Since automatic waterers can become plugged and there is no beneficial effect of extra salt in a diet, restrict added salt to no more than 0.5% of the diet.

Basal ingredients are poor sources of sodium. For example, cereal grains generally contain less than 0.05% sodium (compared with a requirement of 0.10%). Vegetable-based protein ingredients are much richer in sodium, containing 0.30 - 0.50%. A good, economical source of sodium is common salt (39% sodium). Feed companies sell four types of salt defined according to colour. White salt contains only NaCl, red salt contains iodine, blue salt contains iodine and cobalt, and brown salt contains trace minerals. For most swine diets, salt will be added as part of the premix or supplement. If the premix contains other sources of iodine or trace minerals, only pure (i.e., white) salt should be added to the diet.

As mentioned above, most swine diets contain 0.30 to 0.50% added salt to ensure the sodium requirement is met. If you wish to add sodium without chloride, sodium bicarbonate is a reasonable choice. Sodium bicarbonate contains about 27% sodium and is available in feed grade forms. Meat meal, fish meal, and milk products often contain considerable quantities of sodium but since they are highly variable, be extremely careful in depending on these ingredients to supply the total sodium requirement.

Drinking water from deep wells sometimes contains considerable quantities of sodium plus other salts. In this case, sodium is often removed from the diet to help alleviate scouring associated with poor quality drinking water. This practice may or may not help pigs adapt to bad water. Take great care to avoid a sodium or chloride deficiency if removing dietary salt. If you suspect water quality problems, request a detailed water analysis that includes both sodium **and** chloride. By estimating water intake (assume 2 kg of water are consumed per kg of feed), you can determine the daily intake of both sodium and chloride. If the pig's requirement for both sodium and chloride is not met by that in the water (it rarely is), at least some salt must be added to the feed. Consult a qualified nutritionist to calculate the minimum amount of salt required.

Remember that water quality can change over time. If feed salt is reduced, ongoing analysis of the water is required to ensure that sodium and chloride intake is maintained. Interestingly, if removing salt from feed has reduced the scouring associated with poor-quality water, a chloride deficiency (which results in reduced feed intake, thus reduced scouring), is likely to have developed. A pig's performance will suffer more as a consequence of the chloride deficiency than it would have due to the water quality problem.

Salt analysis of a diet is determined by measuring either sodium or chloride and adjusting it to reflect total salt. Table 3-16 provides information for conversion of sodium, chloride, and salt values.

Table 3-16. Calculating 'Salt' Values from Sodium or Chloride Assays in Swine Diets

Salt	Sodium (%)	Chloride
0.1	0.04	0.06
0.2	0.08	0.12
0.3	0.12	0.18
0.4	0.16	0.24
0.5	0.20	0.31
0.6	0.23	0.37
0.7	0.27	0.43
0.8	0.31	0.49
0.9	0.35	0.55
1.0	0.39	0.61

To determine a diet's 'salt' content, locate the appropriate sodium or chloride value from the chemical analyses and identify the salt content on the same line. For example, if an analysis revealed a sodium content of 0.20%, the diet contains 0.5% salt. The table can also be used to determine the amount of sodium and chloride present if the amount of salt is known. This approach makes one important assumption — that sodium and chloride are being supplied largely by salt. In **most** diets, this assumption is true.

It is important to note, however, that other dietary components which supply chloride or sodium alone may make this table invalid. For example, some diets contain considerable amounts of choline chloride, a source of the vitamin choline. Some diets, notably pig starters, will contain lysine hydrochloride, a source of the amino acid lysine. Both chloride sources could bias the salt value if chloride is used to estimate salt content. Thus, if a diet is found to contain excessive 'salt', be sure to consider the method of analysis before worrying about a possible formulation or mixing error. Consult a nutritionist if you suspect a problem.

Chloride

Chloride, like sodium and potassium, plays a major role in water and acid-base balance. However, it also performs a number of independent functions, including the formation of acid to support digestion in the pig's stomach.

Chloride is often supplied in the diet as part of table salt, which is sodium chloride. The nutritionist considers sodium and chloride as independent components of a diet. A diet can be quite adequate in sodium and be deficient in chloride because they are supplied in different proportions by the basal ingredients. Standard practice now includes 0.30 to 0.50% salt in the swine diet formula. This practice will provide 0.18 to 0.30% chloride, sufficient to meet the pig's requirement of about 0.15%.

A pig can handle large quantities of excess chloride in the diet, provided it has a consistent supply of fresh drinking water available. A pig's kidneys are very efficient in excreting excess sodium and chloride.

Chloride can be added to swine diets independent of sodium by removing the salt and replacing calcium carbonate (limestone) with calcium chloride. Calcium carbonate contains about 38% calcium; calcium chloride, in the anhydrous form, contains about 36% calcium and 64% chloride. Hydrated forms, that is those forms in which water is chemically bound to the mineral, contain less calcium and chloride. Chloride can also be added as potassium chloride (47% chloride) or ammonium chloride (66% chloride).

Some ground water contains excessive levels of sodium, which causes scouring and poor pig performance. In an attempt to minimize the effect of excess sodium in the water, salt, containing sodium chloride, is removed from the feed. Although this action may provide some relief, a chloride deficiency may result since water rarely contains much chloride. Therefore, even partial removal of dietary salt requires some care; consult a qualified nutritionist since a deficiency in chloride will depress feed intake and slow growth rate.

Magnesium

About two-thirds of the total magnesium in the body is found in bone. Magnesium is important in stimulating the activity of many enzymes that catalyse chemical reactions in the body. It is also required for normal nerve and muscle function, and for fat and protein utilization.

Like potassium, common feed ingredients supply sufficient magnesium to meet the pig's normal requirements. For example, a cereal grain-based diet will contain about 0.1% magnesium, more than twice the pig's requirement. If magnesium must be supplemented, magnesium oxide (51-59% magnesium) can be used.

Potassium

Potassium is an important mineral. It helps to maintain both water and acid-base balance, supports the transport of nutrients across cell membranes, and is involved in maintaining heart rate.

Potassium tends to be overlooked in nutrition because natural ingredients supply more than enough of it to meet a pig's requirement. Common protein supplements, such as soybean or canola meals, are particularly good sources of potassium. For this reason, combined with the fact that cereal grains often supply all the potassium the pig requires, a potassium deficiency is not usually a concern in practical diets.

Excess potassium may depress the absorption of many nutrients from the intestinal tract but this situation appears to require dietary levels in the range of 2.0% (practical diets contain less than 1% potassium) combined with a wide potassium:sodium ratio.

Potassium rarely needs to be supplemented to healthy swine, but if it does, potassium bicarbonate (38.0% potassium) and potassium chloride (50.5% potassium) are logical choices.

Sulphur

Most of the sulphur present in a pig's body is found in the amino acids, methionine and cystine. Practical diets are never deficient in sulphur *per se* and supplementing a diet with pure sulphur is not required. However, the sulphur amino acids need to be added via the protein supplement to meet the pig's requirements. (see Amino Acids)

Microminerals

The microminerals required in a pig's diet are discussed in the following sections. Some microminerals are present in sufficient quantity in basal ingredients and are not normally supplemented. Others are routinely supplemented to prevent deficiency symptoms. Table 3-17 summarizes the information on the microminerals including those which are normally supplemented in practical diets, maximum tolerable limits for the pig, and common supplemental sources.

Cobalt

Although there is some evidence that cobalt may be involved in several bodily functions, cobalt's major role is as a constituent of vitamin B_{12}. A pig's requirement for cobalt is very low; if vitamin B_{12} is properly supplemented, there is no need to add additional cobalt to swine diets.

Copper

Copper is essential for formation of red blood cells. A copper deficiency may lead to anemia, a type very different from that caused by an iron or vitamin B_{12} deficiency. Copper plays an important role in certain enzyme systems, most importantly those involved in energy metabolism. Finally, copper is required for normal hair pigmentation.

Although a copper deficiency is very rare in swine, copper is always supplemented in a pig's diet. Normally, only 6-12 ppm is required. Usually this amount is supplied by copper oxide (75% copper) or copper sulphate (25% copper), the latter being the more available source of copper. Metallic copper is poorly absorbed so is not used in diets.

Table 3-17. Maximum Tolerable Limits and Supplemental Sources of the Microminerals.

Mineral	Supplemented	Suggested Upper Limit, mg/kg[1,2]	Source Name	Micromineral Content[3]
Copper	Yes	250 (125)[4]	Copper sulphate	25%
			Copper oxide	75%
Cobalt	No	10	-	
Iodine	Yes	400	Calcium iodate	63.5%
			Potassium iodide	76.0%
			E.D.D.I.	79.5%
Iron	Yes	3000	Ferrous sulphate	20.0-32.0%
			Ferrous carbonate	36.0-40.0%
			Ferrous fumarate	32.0%
Manganese	Yes	400	Manganous oxide	55.0-65.0%
			Manganous sulphate	27.0-28.0%
Selenium	Yes	2 (0.3)[4]	Sodium selenate	40.0%
			Sodium selenite	45.0%
Zinc	Yes	1000	Zinc oxide	70.0-80.0%
			Zinc sulphate	36.0%

[1]As recommended by National Research Council 1980.
[2]Upper limits based on nutritional toxicity. These limits may differ from those contained in the Feeds Regulation 1983.
[3]Exact concentration may vary depending on the source. Actual nutrient composition should be determined by analysis.
[4]Legal upper limit according to the Canadian Feeds Act (see chapter 11).

Copper sulphate, also called 'bluestone' because of its blue colour, was a popular disinfectant in the days before more powerful and effective agents were discovered. For example, copper sulphate was used in foot baths to treat lame animals.

Copper is now added to swine diets in high levels to act as an inexpensive growth promotant. It is a more effective growth promotant in diets for starter and grower pigs than for finishing pigs. Adding up to 125 ppm copper (from copper sulphate) to feed is legally permitted in Canada. This amount is well above the amount required for nutritional purposes but costs less than one dollar per tonne.

Adding copper sulphate to a diet at growth promoting levels will produce black sticky feces in pigs. Also, in regions of high livestock density, the use of copper as a growth promotant has sparked criticism due to the potential accumulation of copper in the soil. Although swine can tolerate copper levels in excess of 250 ppm, sheep have been found to be highly susceptible to copper toxicity. Total dietary copper levels for sheep should not exceed 25 ppm. Consequently, swine diets containing copper at growth promotant levels must not be fed to sheep.

Chromium

Until recently, chromium was not considered an essential nutrient for swine. Recently, however, considerable interest has been generated in the effect of chromium and chromium-containing feed additives on the performance of growing-finishing pigs and sows. Chromium, via its involvement with the so-called glucose tolerance factor, may be required for the utilization of large amounts of sugars. There are also some indications that chromium may improve the animal's immune status and increase the effectiveness of insulin. Insulin, produced by the pig, is an important hormone that is required for energy and amino acid utilization.

Several studies have demonstrated that including inorganic chromium in practical swine diets does not affect animal performance. Other studies have shown that adding certain chromium-containing compounds, such as chromium picolinate, to finishing pig diets improves animal performance, especially the lean yield in the carcass and reproductive performance in sows. Further research is required to determine the optimum level of chromium and the form in which it should be included in pig diets and the conditions under which it is most effective.

Iodine

Iodine's main role in the body is as part of the hormone, thyroxine. Thyroxine, produced by the thyroid gland, is involved in regulating a pig's overall metabolic rate. An iodine deficiency, resulting in impaired thyroid function, will have a serious effect on swine growth and productivity.

Iodine deficiency leads to a condition known as goiter, which refers to an enlargement of the thyroid gland. Goiter can be observed as a swelling in the neck where the thyroid gland is located. Goiter causes reproductive failure or the birth of weak or dead, hairless piglets.

Goiter is not caused only by a dietary deficiency of iodine. Certain ingredients in the diet impair iodine utilization by the thyroid gland. The highly successful rapeseed breeding program, which resulted in the development of canola, was in part motivated by a need to remove glucosinolates, well-known goitrogenic compounds in rapeseed meal. Canola meal, with very low levels of glucosinolates, can be used in swine diets (including those of breeding animals) without fear of impairing thyroid function.

Primary iodine deficiency is prevented by including iodine in the mineral premix. Various forms of iodine can be used including potassium iodide (68.5% iodine), calcium iodate (63.5% iodine), or EDDI (ethylene diamine dihydro-iodide; 79.5% iodine). Adding iodized salt (0.007% iodine) at the rate of 2 kg per tonne of feed provides sufficient iodine to meet the pig's requirement. Feeds of marine origin, such as fish meals, are also rich sources of iodine.

Iron

Iron, a component of hemoglobin in the blood, is required to help the blood transport oxygen from the lungs to the body tissues. An iron deficiency can be very serious because the oxygen-carrying capacity of the blood is impaired. Iron is also a constituent of many important enzymes throughout the body. Symptoms of deficiency include poor vigour, lethargy, and a pale, white skin colour.

Iron is always supplemented in pig diets, although pigs would probably do quite well without it. A pig's requirement for iron is not very high and its body has the ability to retain iron very well, especially if dietary sources are scarce. Furthermore, as the need for iron rises, so does the ability of the pig's gut to extract iron from the diet. If market pigs or sows appear iron deficient, the cause is more likely a bleeding ulcer, or other illness, than a dietary deficiency. However, iron is very inexpensive and is added to the diet as cheap insurance.

A definite exception to the pig's limited need for iron is the neonatal pig. Neonatal pigs grow very rapidly and require a great deal of iron to support this growth. Sow's milk is a poor source of iron so supplements are imperative. Injectable iron in a single dose of approximately 150 mg should be administered no later than 3 days of age. A second injection may be given at approximately 21 days (see Chapter 7).

If an iron injection causes sudden mortality, the little pigs are possibly suffering from a vitamin E and/or selenium deficiency. If this is the case, the solution is to treat the sow herd with either injectable vitamin E/selenium or increase the quantities of each element present in the diet.

An iron deficiency leads to anemia, which in turn causes stunted growth and reduced disease resistance. Some producers have seen almost 'magical' recovery from scours in pigs 2 to 4 weeks of age merely by providing iron that was deficient earlier in the pig's life. Avoid extreme excesses, however — some research suggests that too much iron may actually predispose young pigs to diarrhea.

Iron should be injected in the neck rather than the ham muscle. The neck location avoids the possibility of staining expensive cuts (e.g., the ham) and making the product undesirable to the consumer.

Ferrous sulphate (20 - 32% iron) is the first choice of iron supplement in a diet. A less desirable second choice is ferrous carbonate (36 - 45% iron) ; iron oxide is nothing more than rust and is of little nutritional value. Iron oxide may appear on some feed labels because it is used as a colouring agent to ensure a uniform red colour. This practice is most common in mineral supplements or premixes. Pigs eating such diets produce red manure due to iron oxide's poor digestibility.

Manganese

Manganese acts as an important enzyme activator so is critical for normal utilization of carbohydrate, fat, and protein in a pig's diet. Lameness is a symptom of deficiency because manganese is involved in bone formation. Manganese deficiency can also impair normal reproductive performance, causing such problems as irregular estrus cycles, late sexual maturity, and weak piglets at birth.

Supplements are required because basal dietary ingredients cannot be relied on to supply sufficient manganese. Manganese is routinely added to the mineral premix, usually as manganous oxide (55 - 65% manganese) or manganese sulphate (27 - 28% manganese), so a manganese deficiency in swine is very rare.

Selenium

The history of selenium as a nutrient is an interesting study. Initially selenium was considered only as a toxic substance, responsible for alkali disease and blind staggers in cattle. More recently nutritionists have learned that animals must have selenium in their diet. Selenium helps the body protect against the breakdown of cell membranes. It works with vitamin E in this regard, so the two elements are often discussed together.

Because selenium was first identified as a toxic substance and more recently has been found to cause cancer, government agencies are very conservative in allowing selenium supplementation of livestock feeds. In Canada, 0.3 ppm can be added to diets for all classes of swine. Supplemented with adequate vitamin E, this amount would appear to be adequate under most circumstances. Nonetheless, reports of selenium deficiency persist, especially in areas where the soil is low in selenium, thus a low natural supply in the grain. Adding more than 0.3 ppm of selenium to a diet requires a veterinary prescription.

Selenium deficiency in pigs result in mulberry heart disease and liver necrosis. But, before adding selenium to a diet in response to a problem with mulberry heart disease, review the situation carefully. If the problem is occurring in recently weaned pigs, supplementation of the starter diet may be of limited value because the piglets will eat very little before succumbing to the disease. In this case, increasing the vitamin E content of the nursing sow diet or injecting pregnant sows with injectable vitamin E-selenium is the preferred course of action. Some additional attention to the diagnosis of mulberry heart disease is also advised; infections of *Strep. Suis* Type II have been suggested as a plausible alternative diagnosis. Discuss your situation with a qualified nutritionist and/or veterinary pathologist before beginning any treatment.

Concerns about selenium toxicity must not be underestimated because the difference between required and toxic levels is so small. While the requirement is in the range of 0.1 to 0.3 ppm, only 7.0 ppm (25 times the requirement), is toxic.

Selenium supplements in the diet are provided by sodium selenite (45% selenium) or sodium selenate (40% selenium). Because selenium is required in such small amounts, 0.7 gm of sodium selenite per tonne will supply 0.3 ppm. Many feed companies use diluted selenium sources to ensure proper distribution in the mix and to avoid the risk of toxicity. In some instances, selenium can be administered by injection, often as a combination of vitamin E and selenium, to deal quickly with suspected problems.

Zinc

Zinc is an important component in a pig's diet. Zinc is a constituent of many enzymes and acts as a co-factor of others. It is also a part of the hormone, insulin.

Zinc deficiency in the pig results in poor overall growth, reduced appetite, and poor hair growth. A specific syndrome in swine, known as parakeratosis, is the result of a zinc deficiency. It shows up as skin lesions which may open and later develop scabs. Parakeratosis is associated with poor growth rate and impaired feed efficiency.

The utilization of zinc can be impaired by excessive calcium in the diet. Indeed, dietary calcium has a profound effect on zinc requirements. At recommended calcium intakes, 50 ppm zinc appears to be quite adequate; excessive calcium can more than double the amount of zinc required to prevent deficiency symptoms. Phytic acid, common in cereal grains and protein supplements of plant origin, also reduces the pig's utilization of zinc.

Zinc should always be supplemented in a swine diet. Consequently, it is included in the mineral premix as zinc oxide (70-80% zinc) or zinc sulphate (36% zinc). As zinc supplied in the form of a sulphate is more available to the pig than zinc supplied in the form of an oxide, zinc sulphate is preferred over zinc oxide.

Recent studies have shown that including extremely high levels of zinc oxide (up to 3000 ppm of zinc) in diets for newly weaned piglets increased feed intake and growth rate. It is speculated that at these pharmacological levels, zinc is effective in controlling *E. coli* scours. However, these levels are higher than is allowed in swine feeds in Canada. In addition, if these high zinc levels are fed for too long, e.g., more than two to three weeks, they may result in zinc toxicosis. Alternative means to control the negative effects of *E. coli* scours are preferred.

Vitamins

Vitamins are one of the six major nutrient classes in a diet. The other classes are energy, protein, minerals, essential fatty acids, and water. A pig requires vitamins to support or stimulate the many chemical reactions that occur in the body as part of normal metabolism. Although they are present in small quantities, vitamins perform very important functions. As is the case with all nutrients, the quantity present is not an indicator of importance.

Vitamins can be analysed but the cost is high. Also, once they are added into a mixed feed, the levels may be too low to be accurately analysed. It is rare to test for vitamins unless a problem arises. Many feed manufacturers test for one or two vitamins, e.g., riboflavin and vitamin A, in spot samples to ensure proper formulation and mixing of premixes.

Deficiencies of a vitamin or group of vitamins must be avoided to maximize swine performance. Unfortunately, the role of vitamins in nutrition has often been misunderstood; vitamins have in many cases been viewed in almost the same way as drugs. For example, vitamin X will prevent spraddle leg or vitamin Y will improve estrous behaviour. Although individual vitamins have specific functions and a deficiency will result in certain symptoms, this does **not** mean that adding additional quantities of a vitamin or vitamins will improve health or performance. As always, the essence of nutrition must be to balance all nutrients according to need and not to assume that one nutrient possesses magical qualities.

At least some vitamins are naturally present in the diet and need not be supplemented. Others are present, but are either poorly available (niacin) or are in amounts well below the requirement (vitamin E) so that supplementation is necessary. Some vitamins, such as vitamin C (ascorbic acid), are synthesized by the pig. Others, such as biotin, are produced by the microbes present in the lower gut. Under some conditions, natural synthesis may be impaired, resulting in greater need for supplementation. For example, sulpha drugs in the feed or water may reduce or even eliminate biotin synthesis in the gut. All vitamins can be produced chemically so that supplementation, when necessary, is not a problem other than cost. Overall, vitamin fortification generally represents less than 4% of the total feed cost.

Identifying vitamin deficiencies is not a simple task because the symptoms are rarely specific. For example, a niacin deficiency impairs appetite and growth rate, and causes severe diarrhea. Many other factors can produce the same symptoms. Consequently, symptoms must be considered in the context of other information, such as feed analysis, herd history, and a thorough review of health status, to ensure an accurate vitamin deficiency diagnosis.

Vitamins are categorized according to solubility characteristics. Vitamins A, D, E, and K are called the fat soluble vitamins. The B vitamins and vitamin C are called the water soluble vitamins. The fat soluble vitamins are stored in the pig's body so that brief periods of dietary deficiency rarely cause a problem because the pig can draw on reserves. The water soluble vitamins, because they are not stored in the body, must be present in the diet on a more or less regular basis.

In Canada, all diets based on cereal grains must be supplemented with vitamins A, D, E, K, and B_{12}, as well as riboflavin, niacin, and pantothenic acid. Sow diets should contain added choline, and probably folic acid and biotin. Other vitamins, if supplemented, are probably being included only as a safety factor.

Vitamin Stability

Vitamin supplements deteriorate with age; certain environmental factors accelerate the rate of deterioration. Agents that tend to stimulate vitamin degradation include moisture, oxygen (air), light, and heat. pH is another concern but the producer can do little to regulate it, for pH regulation is the feed supplier's responsibility. A producer must be aware of the situations that increase vitamin breakdown and avoid them as much as possible. In general, the fat soluble vitamins are less stable than the water soluble vitamins. There are exceptions; for example, vitamin C is very unstable in the diet.

Vitamin supplement manufacturers have recognized the problem of stability. Vitamins A, D, and E are supplied encased in gelatin that protect them from breakdown, but which still allow for absorption in the gut. These gelatin beads also contain anti-oxidants which provide further protection for the vitamins inside.

The presence of trace minerals, such as copper and iron, in the diet tend to increase the breakdown of some vitamins. Poor quality fats may also cause a problem. The concern regarding trace minerals is greater in premixes than complete feeds since in a premix, trace minerals are present in much higher relative concentrations and are thus in more intimate contact with vitamins.

Choline chloride is a particular stress factor for vitamins. Breakdown can be as much as three to four times higher in premixes containing choline chloride than those without it.

Table 3-18 summarizes information on the stability of individual vitamins. To ensure maximum vitamin stability, premixes should be stored in a cool, dry, dark location and inventories should be turned over reasonably quickly, particularly in the summer when the temperature and humidity rise.

A premix containing only vitamins can be stored up to 6 months with minimal deterioration, except for folic acid, which deteriorates more rapidly. Vitamin-trace mineral premixes, sometimes called micro-premixes, which do not contain calcium, phosphorus, or salt, can be stored up to 4 months. However, losses of some vitamins under good storage conditions will exceed 10%. Folic acid and vitamin C, if present, are the least stable vitamins in such premixes.

Macro-premixes, which contain supplements of all vitamins and minerals (micro and macrominerals) should not be stored for more than four months, since losses in excess of 10% can occur for many vitamins including folic acid, pyridoxine, vitamin D_3,vitamin A, thiamine, menadione (vitamin K), and if present, vitamin C.

The maximum time for storing complete feeds is probably 4 months; losses of 10% or more will occur after that period. Vitamins C and K, and thiamine will be particularly affected.

Acceptable storage periods can be increased if extra vitamins are added to the premix. By providing large overages, shelf-life is extended because losses due to storage are offset by higher original vitamin concentrations. Actual overages can be calculated based on expected losses due to processing and length of the storage time (Table 3 - 18).

Vitamin A

Vitamin A, known chemically as retinol, plays a major role in vision, bone development, reproduction, and in the formation of mucous membranes (i.e., lining of the lungs and intestine). Vitamin A deficiency can result in night blindness or un-coordination. In sows, a deficiency may result in the birth of dead, weak, or malformed piglets. Signs of vitamin A deficiency include fetuses with small or no eyes, a cleft palate, or hydrocephalus. These symptoms, however, can be caused by other factors, including some of genetic origin, so a vitamin A deficiency cannot be diagnosed merely on the basis of malformed piglets. Vitamin A deficiency in the sow will not cause abortion. In any event, vitamin A deficiency is rare now that diets are properly supplemented.

Vitamin A is readily destroyed when exposed to heat, moisture, and light. The process can be accelerated if the vitamin is in close contact with trace minerals and/or unstable fats. Vitamin A activity can best be maintained by storing the feed in a dry, cool, dark area.

Vitamin A in feed is supplied as esters (compounds), such as vitamin A palmitate or vitamin A acetate, which are more stable than other forms. They are also manufactured in tiny gelatin capsules that reduce deterioration rate and ensure both stability and uniform distribution. Anti-oxidants are often added to provide further protection. Perhaps the greatest danger exists in vitamin-mineral premixes that contain both vitamin A and trace minerals. For this reason, it is wise not to keep such premixes longer than 4 months. Because modern vitamin A sources are stable and because most premixes contain far more vitamin A than a pig actually requires, a 4 month storage period should not be excessive provided the premix is kept dry and is not heated or exposed to light.

Vitamin A concentration is expressed in International Units (IU), an arbitrary scale that permits comparison among different sources. One IU of vitamin A is equivalent to 0.3 ug of retinol (vitamin A alcohol), 0.344 ug of retinyl acetate (vitamin A acetate) or 0.55 ug retinyl palmitate (vitamin A palmitate).

Fish oils are good natural sources of vitamin A. Alfalfa meal contains carotenoids which are chemicals that the animal can convert to vitamin A. As a rule, one can assume that for swine, 1 mg of Beta-carotene is equivalent to 260 IU of vitamin A. There are some indications that Beta-carotene itself plays a role in swine reproduction, independent of vitamin A. However, more research is required in this area. For example, some studies indicate that Beta-carotene appears effective only when administered via injections and not when included in the feed. Other studies suggest that vitamin A, when administered in an injectable form, may enhance reproductive performance in sows just like injectable Beta-carotene.

Beta-carotene is widely distributed in certain foods. Most green materials, such as alfalfa, are relatively rich in Beta-carotene since it is generally associated with chlorophyll (the compound which imparts the green colours in plants). There are exceptions, such as carrots and tomatoes, which contain carotene but not chlorophyll. A compound called xanthophyll, although part of the carotenoid family, has no vitamin A value. It is often used in poultry rations based on cereal grains to provide the yellow pigment in egg yolks, but xanthophyll has no value in swine diets.

Hays may lose much of their vitamin A activity if left in the sun too long to cure, since heat and sunlight destroy the carotenes. Cereal grains contain essentially no vitamin A.

Vitamin D

A pig requires vitamin D for the proper utilization of calcium and phosphorus, including stimulating the gut to absorb them. Vitamin D also plays a very important role in normal bone metabolism. A vitamin D deficiency is most likely to appear as lameness or other signs of disturbed calcium and phosphorus utilization. Pigs that are deficient may have swollen joints, broken bones, or stiffness. However, various infectious agents can also cause stiffness and swelling so determination of a vitamin D deficiency cannot be made without detailed diagnostic tests.

Vitamin D is formed naturally by exposure of the pig's skin to sunlight. The ultraviolet rays in sunlight activate an enzyme responsible for converting a natural compound (7-dehydrocalciferol) into vitamin D. For this reason, pigs housed indoors require preformed vitamin D supplements in their diet.

Stability concerns, similar to those described for vitamin A, also exist for vitamin D, although it is a somewhat more stable compound. Modern processing methods, generous diet formulation standards, and proper storage practices combine to overcome potential concerns. In terms of natural sources, most fish oils are excellent. Cereal grains contain no vitamin D.

Table 3-18. Stability of Vitamins in Premixes and During Pelleting and Extrusion.

	Stability				
	Very High	High	Moderate	Low	Very Low
Vitamin	Choline Chloride B_{12}	Riboflavin Niacin Pantothenic acid, E Biotin	Thiamine Mono Folic Acid Pyrodoxine D_3 A	Thiamine HCl	Menadione Ascorbic acid
			(losses/month)		
Premixes without choline and trace minerals	0	<0.5%	0.5%	1%	2%
Premixes with choline	<0.5%	0.5%	2%	4%	6%
Premixes with choline and trace minerals	<0.5%	1%	8%	15%	30%
Pelleting	1%	2%	6%	10%	26%
Extrusion	1%	5%	11%	17%	50%

Source: BASF Technical Bulletin.

There are two chemical forms of vitamin D referred to as vitamin D_2, also called ergocalciferol, and vitamin D_3, known as cholecalciferol. Vitamin D_3 is the only form available in commercial supplements since poultry have difficulty utilizing Vitamin D_2 and because the cost of manufacturing vitamin D_2 is greater than that for vitamin D_3. Vitamin D activity is expressed in International Units, where 1 IU is equivalent to 0.025 ug of pure vitamin D_3.

Excess vitamin D must be avoided because it can lead to many health problems, such as accumulation of calcium in the kidney and blood vessels which, in severe cases, will cause death. In some parts of the world, high potency vitamin D preparations are used as rat poison.

Vitamin E

Vitamin E is actually a general name for a group of compounds called tocopherols and tocotrienols. Alpha-tocopherol is the most active and also the most widespread in nature. A pig requires vitamin E for many functions, including normal muscle activity and reproduction. Vitamin E helps to prevent the membrane surrounding individual cells from deteriorating, influences the production of various hormones, and defends against infection. Because of its involvement in maintaining cell membranes, increased vitamin E levels in pig finisher diets have been related to reduced drip losses and reduced incidence of pale meat in swine and beef carcasses.

Vitamin E deficiency symptoms include muscle weakness and liver damage. Reproductive impairment is often used as a sign of vitamin E deficiency, but because the sow can store vitamin E for a long time and in considerable quantities, effects on litter size are extremely rare.

Researchers now know that vitamin E acts with selenium to protect against some diseases. Thus, nutritionists take great care to ensure that both vitamin E and selenium are properly supplemented in a diet. If one is deficient, the requirement of the other is raised. Conversely, a high dietary level of one reduces, but does not eliminate, the need for the other. A vitamin E deficiency can be prevented by supplying a properly balanced diet containing both vitamin E and selenium supplements.

On occasion, a symptom of vitamin E deficiency, hypersensitivity to iron injections in young pigs, is reported. Piglets die soon after receiving an iron injection due to iron's oxidizing effects. The solution is to treat the pregnant sow with vitamin E/ selenium injections so that she transmits protection to the fetus directly and to the piglet, after farrowing, via her milk.

Mulberry heart disease is occasionally diagnosed in swine and is attributable to a dietary deficiency of vitamin E and/or selenium. Care must be taken in diagnosing mulberry heart disease. Infection with *Strep. suis* Type II can induce similar symptoms. If you suspect a problem, consult a veterinary pathologist familiar with the disease.

Vitamin E in the diet is inherently unstable, especially in the presence of rancidifying (improperly stabilized) fats. Vitamin E is also expensive so that over-formulation, a common practice with vitamins A and D, is less common. Therefore, vitamin E represents a greater concern with respect to the longevity of vitamin-mineral premixes. The four month feed storage rule still applies provided care in storage and handling is exercised.

Vitamin E requirements are expressed in mg, International Units (IU) or United States Pharmacopeia (USP) units. It is important to be able to interchange these measurements because different sources may be expressed in different ways. One IU of vitamin E is equivalent to 1 USP unit which in turn equals 1 mg of dl-a-tocopheryl acetate, 0.74 mg of d-a-tocopheryl acetate, 0.91 mg of dl-a-tocopherol, and 0.67 mg of d-a-tocopherol. The acetate form is preferred because it is more stable.

Vitamin E is present in many feedstuffs but can be destroyed by curing, artificial drying (of grains), and storage. The tocopherol content of many feed ingredients are listed in Table 3-19. However, in practical swine diets, sufficient supplemental vitamin E is added to meet requirements so the natural sources provide an additional safety margin.

Table 3-19. Alpha-tocopherol Content (mg/kg) of Feed Ingredients.

Ingredient	Mean	Range
Alfalfa meal	49.8	3 - 106
Barley	7.4	4 - 11
Blood meal	1.0	0 - 4
Canola meal	14.5	10 - 19
Corn	3.1	0 - 21
Corn germ	22.7	2 - 49
Corn gluten meal	6.7	3 - 12
Cottonseed meal	17.3	3 - 32
Feather meal	7.3	5 - 8
Linseed meal	4.0	-
Meat meal	1.2	0 - 5
Oats	7.8	4 - 11
Peanut meal	2.7	2 - 4
Poultry by-product meal	6.0	0 - 16
Rice	2.3	2 - 2.4
Rye	9.0	2 - 14
Sorghum	5.0	1 - 16
Soybeans	21.0	-
Soybean meal	2.3	0 - 8
Sunflowers	10.4	4 - 18
Sunflower meal	5.0	-
Wheat	11.6	5 - 30
Wheat bran	16.5	10 - 25
Wheat middlings	20.1	2 - 41
Whey (dried)	0.3	0 - 1

Source: Hoffman LaRoche Ltd. 1988

Vitamin B_{12}

Vitamin B_{12}, also known as cyanocobalamine, is required in extremely small quantities in the diet. It used to be called the 'animal protein factor' because before Vitamin B_{12} was discovered, producers knew that animals receiving diets containing ingredients solely of plant origin would develop pernicious anaemia. Now we know that plants are incapable of producing vitamin B_{12} so diets based on grains are completely devoid of it. Today, synthetic vitamin B_{12} is readily available so pigs can grow quite well on diets devoid of animal products. The vitamin is synthesized by bacteria so that pigs with access to feces can obtain vitamin B_{12} from this source. Vitamin B_{12} cannot be absorbed from the gut without the aid of the 'intrinsic factor', which is secreted by the stomach of healthy animals. Absence of intrinsic factor, even with adequate vitamin B_{12}, will result in pernicious anaemia.

Vitamin B_{12} deficiency results in anaemia, slow growth, poor co-ordination of the hind legs, and rough hair coat. Longer term deficiency causes nerve degeneration. The impact of a deficiency is much greater in young animals than adults. Severe cases can result in high mortality among affected animals. Vitamin B_{12} deficiency can also alter the structure of backfat in pigs leading to the accumulation of odd chain fatty acids.

Cobalt is a part of vitamin B_{12}. Cobalt's main function in the body is to work within vitamin B_{12}'s structure. Diets supplemented with vitamin B_{12}, need no extra cobalt. Synthetic sources, simply called vitamin B_{12}, are available for use in diets.

Vitamin C

In the animal kingdom, only a few species, including man and monkeys, require supplemental vitamin C (ascorbic acid). All other species, including pigs, possess an enzyme that converts glucose to vitamin C. There is some indication that young pigs may benefit from the addition of vitamin C to their diet, but the available information is not conclusive.

Biotin

Biotin is involved directly or indirectly in energy and carbohydrate metabolism, fat synthesis and breakdown, amino acid metabolism, protein synthesis, nitrogen excretion, and the maintenance of hair, skin, nerves, and sex glands. A deficiency results in impaired growth rate, dermatitis, loss of appetite, and spasticity of the hind legs.

Biotin is found in cereal grains and other ingredients commonly fed to swine. The availability of natural biotin in most feedstuffs tends to be poor and variable. The biotin in corn is more available than that in wheat, but there is much less of it. Thus, the earlier belief that supplemental biotin is not required in swine diets has been reconsidered and common practice now includes biotin in diets for the breeding herd and growing boars and gilts that may be selected for breeding.

Avidin, a naturally occurring compound in egg whites that binds with biotin and makes it nutritionally unavailable, can be added to swine diets to induce deficiency symptoms. On the basis of this research, we now understand that sows deficient in biotin may develop hoof lesions that can lead to premature lameness. Various studies show that adding biotin to sow diets increases reproductive efficiency. Wheat or barley based sow diets are generally supplemented with 150 to 250 mcg of biotin per kg of diet. Much higher levels are used in some cases, but the benefits are far from clear. Fifty to one hundred (50-100) mcg of biotin may be added to barley or wheat based diets for growing-finishing pigs. Since biotin is an expensive vitamin, adding an excessive safety margin does not make economic sense. When required, biotin is available in synthetic form.

Choline

Choline, unlike other vitamins, is required in the diet in a high concentration and acts more as a structural component of the body rather than in support of chemical reactions. The body uses choline to produce chemical messengers called neurotransmitters which allow nerves to send messages throughout the body. Choline also forms part of cell membranes, provides a surface active agent required by the lungs, is involved in fat and cholesterol metabolism, and acts as a precursor for the formation of the amino acid, glycine. Signs of choline deficiency include reduced weight gain, rough hair coat, decreased red blood cell count, and unbalanced and staggering gates.

Choline deficiency has been implicated as a cause of spraddle leg in swine although there is very little scientific support. Many experiments have evaluated the effect of choline on spraddle leg and none have concluded that choline was beneficial. The use of choline to prevent spraddle leg is questionable and should be carefully considered from a cost:benefit perspective. Some producers spend as much as five or six dollars per tonne of sow diet to provide generous supplementation of choline. Using good flooring materials that improve footing in the farrowing crates has proven to be a more effective solution to the problem at less cost. Other approaches, such as tracing genetic predisposition in the breeding herd and removing parents of piglets that seem predisposed to spraddle leg, is also effective in some herds.

The pig can synthesize choline from the amino acid, methionine. Thus, the dietary requirement for supplemental choline will depend on the pig's methionine status. Choline is supplied by the salt, choline chloride. It is very hygroscopic (attracts water) so must be carefully stored. Pure choline chloride contains 86.78% choline. Commercial supplements, available in dry form, contain either 50% or 60% choline chloride. Liquid choline chloride (70%) is also available.

Folic Acid

Folic acid is the name given to the vitamin, while the term, folacin, refers to compounds derived from the vitamin. Folic acid is involved in a number of functions, including cell division and growth, and amino acid and nitrogen metabolism. Folic acid deficiency results in anemia (different from that caused by iron deficiency), reduced weight gains, and fading hair colour.

Until recently, it was believed that normal dietary ingredients plus gut synthesis provided sufficient folic acid for pigs. Therefore, most swine diet premixes did not contain supplemental folic acid. However, recent information suggests that folic acid improves reproductive performance in sows.

Prolonged administration of sulpha drugs inhibits growth of the bacteria that synthesize folic acid in the gut. The need for supplementation may depend on the use of drugs in a particular herd.

Menadione

Menadione, a more common name for vitamin K, is involved in calcium and vitamin D metabolism. The blood requires vitamin K to form clots; a deficiency results in prolonged clotting time and in severe cases, haemorrhaging. A compound called dicoumarol, found in spoiled sweet clover, reduces the blood's prothrombin content and raises the requirement for menadione supplementation. Certain mycotoxins in the diet may have the same effect. Sulpha drugs can reduce bacterial synthesis and place greater pressure on dietary sources of menadione.

Vitamin K is supplemented in diets by a number of compounds, such as menadione dimethylpyrimidinol bisulphite (MPB-22.7% menadione), and menadione sodium bisulfite complex (MSBC-33.0 or 16.5% menadione). Alfalfa meal is a rich, natural source of menadione.

Niacin

Another name for niacin is nicotinamide, which is the biologically active form of the vitamin. Niacin is a relatively stable compound not adversely affected by heat. It is involved in the metabolism of many dietary components including fats, carbohydrates, and proteins. Because of niacin's central role in metabolism, nutritionists are careful to avoid a deficiency. Deficiency symptoms include reduced weight gain, dry skin, poor appetite, and diarrhea.

Cereal grains contain considerable quantities of niacin but its availability in corn, wheat, oats, and sorghum is poor. Conversely, the niacin in soybeans is highly available. Niacin is readily available in synthetic form at a reasonable cost for supplementation in swine diets.

Tryptophan in the body can act as a precursor for niacin; diets containing excess tryptophan require less niacin. A diet marginal in tryptophan will place greater pressure on the need for niacin. However, tryptophan is the second or third limiting amino acid in diets based on corn, so dietary tryptophan is unlikely to provide appreciable amounts of niacin. Theoretically, 50.0 mg of tryptophan will provide 1.0 mg of niacin.

Pantothenic Acid

Pantothenic acid was formerly known as vitamin B_5. As a component of one specific co-enzyme, co-enzyme A, pantothenic acid is important for fat and carbohydrate metabolism. Deficiency symptoms include slow growth, diarrhea, dry skin, reduced immune response, and a peculiar behaviour known as 'goose stepping' in the hind legs.

The name pantothenic acid is derived from the Greek word 'pantothen' which means 'from everywhere'. As its name suggests, pantothenic acid is found in many feed ingredients. Barley, wheat, and soybean meal are good sources, but biological availability in corn and sorghum is low. Although cereal grains are good sources of the vitamin, swine diets are generally supplemented with the synthetic form called d-calcium pantothenate (88.3% d-pantothenic acid). The form called dl-calcium pantothenate provides 44.0% d-pantothenic acid, since the l-isomer is biologically inactive.

Pyridoxine

Pyridoxine was formerly called vitamin B_6. Pyridoxine, like other vitamins, plays an important role in enzyme function. Over 50 pyridoxine-dependent enzymes have been identified. Pyridoxine is particularly important in amino acid metabolism and the formation of neurotransmitters, the chemical messengers of the nervous system. Deficiency symptoms include reduced appetite and growth rate. In severe cases, nervous disorders, including convulsions, occur.

Cereal grains are good dietary sources of pyridoxine. Because of the wide distribution of pyridoxine in common feed ingredients, pyridoxine deficiency in swine is very rare and most diets, with the possible exception of starter diets, are not normally supplemented.

Riboflavin

Riboflavin is a critical co-factor in energy metabolism and also plays a role in fetus development. Formerly called vitamin B_2, riboflavin is supplemented in all swine diets because cereals are a poor natural source. Whey powder, commonly used in starter diets, is the only ingredient used in swine diets that is a good source of riboflavin. Supplemental riboflavin is available commercially as a 96% pure powder.

Riboflavin deficiency results in anestrus in gilts, cataracts, a stiff gait, and reduced growth rate. It is also teratogenic, meaning a deficiency results in the birth of deformed piglets.

Thiamine

Thiamine was once called vitamin B_1. A pig's requirement for thiamine increases in proportion to its energy intake because thiamine is required to maintain normal energy metabolism. Symptoms of deficiency include depressed appetite, vomiting, depressed body temperature, and a slower than normal heart rate. Deficiency (for research purposes) can be induced by feeding raw fish, which contains the enzyme, thiaminase, that destroys thiamine.

Grains are generally good sources of thiamine. Thiamine is present in the germ and hull portion of cereals so wheat germ and bran contain very high levels of thiamine. Flour, because of its limited quantity of wheat germ and bran, is a poor source of thiamine . Diets are not generally supplemented with thiamine because most common ingredients are rich sources of the vitamin. Some nutritionists believe supplementation is required, especially in a young pig's diet, so small amounts (1 mg/kg) may be added to starter diets. Synthetic thiamine is usually provided as thiamine hydrochloride (89% thiamine) or thiamine mononitrate (92% thiamine).

Essential Fatty Acids

As indicated previously, dietary fats are made up of sub-units called fatty acids. At least one, linoleic acid, is essential in a pig's diet. Linoleic acid, a member of the omega-6 family of fatty acids, is a dietary essential because it performs a specific role and cannot be synthesized from other compounds. Linolenic acid, a member of the omega-3 family of fatty acids, may also be required in the diet. A third fatty acid, arachadonic acid, also a member of the omega-6 family of fatty acids, can be considered a semi-essential fatty acid. Pigs require arachadonic acid but can synthesize it from linoleic acid if supplied in sufficient quantities in the diet.

The essential fatty acids (EFA) perform a number of functions. They become an important part of cell membranes, thus help to ensure that cells function normally. They are also involved in the synthesis of a group of very important hormones called prostaglandins. These hormones are required for many body functions, including reproduction.

The requirements for essential fatty acids in pig diets are not well established. The recent interest in the role of essential fatty acids in human health has revived the interest in the metabolism and utilization of essential fatty acids by pigs as well. There is, for example, considerable debate on the efficiency with which pigs can convert linolenic acid to other polyunsaturated fatty acids that belong to the family of omega-6 fatty acids and that are required for normal animal metabolism and reproduction. Some studies suggest that the ratio of omega-6 to omega-3 fatty acids in the diet is as important for the conversion of these omega-3 fatty acids as the levels of these fatty acids in the diet itself. An essential fatty acid deficiency is unlikely in normal diets for growing swine because the requirement appears to be very low (approximately 0.1 - 0.3% of the diet) and because vegetable fats tend to be good sources. Even the small amount of fat present in wheat or barley apparently supplies more than sufficient EFA to meet requirements.

The actual requirements for EFA by sows and boars, however, are difficult to establish. The synthesis of some important reproductive hormones depends on EFA; the requirement for the breeding herd is suspected to be substantially higher than it is for growing animals. Because EFA is stored in body fat reserves, any signs of deficiencies in sows may not occur until the third or fourth parity. Based on a factorial estimation, sows may require 0.75% linoleic acid in the diet. If this estimate is indeed correct, a barley-soybean meal based diet may be deficient in linoleic acid. No estimates are available for the requirements for linolenic and arachidonic acid in swine.

An EFA deficiency will impair growth rate and feed utilization, cause dry, scaly skin, and possibly result in hair loss. Reproductive performance also suffers. One experiment demonstrated that EFA deficiency resulted in impaired water holding capacity of muscle, and that heart muscle structure and colour changed.

Vegetable fats are rich sources of EFAs. The reason cereal-based diets present a deficiency risk is because barley and wheat contain much less fat than corn. The recent practice of adding vegetable oil, or whole seed canola or soybeans to sow diets should remove all concern about a possible deficiency. The fact that the requirement has not been defined, however, leaves some room for question.

Water

Water is often called the 'forgotten nutrient' because it is so often ignored. Yet, water is as important as any other dietary component and must be supplied in sufficient quantities to ensure maximum productivity. Water is critical to life and good health. For detailed information on water, refer to chapter 12.

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