National Swine Nutrition Guide

Energy Sources for Swine Diets

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Introduction

Energy fuels maintenance, growth, reproduction and lactation processes and physical activity. Total energy content of a feed ingredient (gross energy) is determined by its chemical composition and is the sum of the gross energies of carbohydrate, fat, and protein fractions. The proportion of gross energy utilized by the animal is dependent on energy digestibility and how the energy is utilized by the animal. Energy concentration represents the largest cost component of swine diets. Thus, information regarding energy values of feed ingredients and their contribution to the diet is of particular importance to reduce diet costs and maximize pig performance.

Utilization of dietary energy by pigs is measured and reported in a standard way. Digestible energy (DE) is gross energy minus fecal energy; metabolizable energy (ME) is DE minus energy lost in urine; and net energy (NE) is ME minus heat losses. This hierarchy of energy measurement provides a framework for characterizing feed ingredients and also a common basis for the use of ingredients in diet formulation. Net energy represents the energy that is available to the pig for maintenance and production and is considered by many to be the most accurate estimate of an animal's need for energy for maintenance and productive purposes [2], although accurate estimates of NE of individual ingredients are difficult to obtain.

Carbohydrates (sugar, starch, and fiber) from cereal grains are the most abundant energy source in typical US swine diets. Fat and oils contribute on average 2.25 times more gross energy than carbohydrates [1], but are included in diets in lower quantities and therefore make a smaller overall contribution to total dietary energy. Protein usually contributes between 15 and 20% of the total energy in the diet.

Objectives

- Discuss feed energy ingredients and usage concepts
- Provide descriptions and a table of ME and NE values and NE:ME ratio for ingredients typically used in US swine diets
- Discuss energy differences among ingredients

Energy Concentration of Feed ingredients

The majority of ME concentrations of feed ingredients listed in the National Swine Nutrition Guide were derived from the swine NRC [1]. Whenever possible, data from recent studies were also considered. Feed ingredient NE values for approximately 40% of the ingredients are growing pig values obtained from the ingredient tables in EvaPig [3]. Net energy values for the other ingredients were calculated from one of the following equations where ME = metabolizable energy, EE = ether extract, ST = starch, CP = crude protein, CF = crude fiber and ADF = acid detergent fiber. Equation NE_1 was used when values for EE, ST, CP and ADF were known or could be reasonably estimated. When ADF was not available, equation NE_2 was used to estimate NE.

$NE_1 = 0.726 \times ME + 1.33 \times EE + 0.39 \times ST - 0.62 \times CP - 0.83 \times ADF$ ($R2 = 0.97$; [2])

$NE_2 = 0.730 \times ME + 1.31 \times EE + 0.37 \times ST - 0.67 \times CP - 0.97 \times CF$ ($R2 = 0.97$; [2])

The net energy value for fats and oils was calculated by multiplying ME by 0.90, the estimated efficiency with which fat is converted from ME to NE [4].

For more information regarding the ME and NE concentration in feed ingredients, please refer to PIG Factsheet 07-07-09 (Composition of Feed Ingredients for Swine).

Energy Sources

The ME, NE, and NE:ME ratio for ingredients commonly used in swine diets are shown in Table 1 (references cited). These single values represent averages based on available data. It is important to recognize that energy value for a specific batch or lot of an ingredient may be different than the value in Table 1 due to variation in chemical composition and digestibility. The values in Table 1 represent reasonable starting points for diet formulation. Over time, experience and performance data should be considered and refinements to these values can be made.

Cereal Grains. Cereal grains typically provide most of the energy in swine diets, have a relatively high concentration of starch, are usually palatable, and highly digestible . The NE:ME ratio for cereal grains ranges from 0.70 to 0.80, suggesting that 70 to 80% of the ME in cereal grains is used for maintenance and production by the pig.

Corn grain is the leading cereal used in the US and contains a greater energy density than other cereal grains. Because of its abundance and high energy concentration, corn is the base to which other cereal grains are compared. Estimates for corn ME and NE concentrations are shown in Table 1. Dry matter content of cereal grains has a significant influence on the ME and NE values used in diet formulation. For example, whereas the corn ME value from Table 1 is 1555 at 11% moisture (89% DM), the ME value of the same corn at 15% moisture would be 1480 kcal/lb and 1428 kcal/lb at 18% moisture. In the US, it would not be unusual for corn to be harvested at 18% moisture, be dried to 15% moisture after harvest and, due to storage moisture losses, be 11% moisture by summer. To derive a good estimate of the ME content of corn or other cereals from Table 1 for use in formulating diets, it is critical to know the moisture content.

Multiple seed companies have commercialized variants of corn with altered chemical composition such as high lysine, nutrient dense, high oil or low phytate corn. These new varieties generally contain greater quantities of fat (oil), which increases the ME and NE concentration compared with traditional, yellow-dent corn, and may have altered content or digestibilities of other nutrients such as lysine or phosphorus. It is important to make adjustments in energy value assumptions if these varieties are used for diets

Sorghum contains slightly less energy than corn and can replace all the corn in swine diets. Wheat is an excellent feedstuff for swine and contains approximately 93 to 94% of the ME and NE of corn; the greater content of amino acids such as lysine should be accounted for when preparing wheat based diets. Barley, millet, and rye contain 83 to 89% of the ME and NE of corn. Triticale, a hybrid of wheat and rye, is similar to wheat in ME and NE. Oats, compared to other cereal grains, contains the least amount of ME and NE. The lower ME and NE concentrations of these cereal grains reflects higher fiber concentration.. However, dehulled/defibered cereals, such oat groats, have similar ME and NE as corn

Cereal grain development can be affected by adverse weather during the growing season (i.e. drought, floods, early frost). The most common result is reduced kernel bulk density (i.e low test weight). Under wet conditions, sprout-damaged grains may be also be observed. Often these ingredients are available to swine producers at attractive prices, but it is difficult to adequately assess the nutritional value. Generally, bulk density/test weight is a poor indicator of the energy content of cereal grains and the nutritional value per pound is unaffected by test weight unless the reduction is severe. Mycotoxin contamination of the grain may increase when adverse weather is experienced during the growing season. For more information on weather damaged grains, please refer to PIG Factsheet 07-06-07 (Utilization of Weather-Stressed Feed Ingredients in Swine Diets).

Grinding to reduce particle size improves nutrient utilization likely because of increased surface area which enhances rate and extent of digestion. Furthermore, pelleting can also improve the efficiency of feed utilization. Both fineness of grind and pelleting should be evaluated for cost benefit. Most studies show improved energy digestibility down to at least 400 microns geometric mean particle size. While fine grinding of corn results in improved feed efficiency, occasionally very fine grinding is implicated in an increase in the incidence of gastric ulcers. Because this is not a consistent observation, there may be underlying conditions that predispose some groups of pigs to gastric ulcers. Sorghum grain is harder and smaller than a corn kernel and finer grinding relative to corn (1/8 or 5/32" screen) is recommended. Wheat tends to flour when processed and therefore it should be coarsely ground (3/16" screen) or rolled. Fine grinding of high fiber cereal grains such as oats and barley, improves digestibility and consequently increases ME and NE content. For more information related to grinding of cereal grains, please refer to the PIG Factsheet 07-04-03 (Swine Feed Processing & Manufacturing).

Cereal grain Co-products: The quantity and availability of grain processing co-products, especially from the ethanol industry, has increased in recent years. Starch, crude protein, fat, and fiber concentrations of these co-products differ from the original grain source. Accurate estimates of the ME and NE in these co-products is necessary for proper diet formulation.

Corn distiller dried grains with solubles (DDGS) is a co-product of the dry milling distillery/fuel ethanol industry. Approximately 2/3 of the corn mass (primarily starch) is fermented to produce ethanol and CO2, and the remaining 1/3 becomes the major component of DDGS. As a result, the concentrations of CP, fiber, and fat in DDGS are approximately 3 times that of corn grain . Recent research suggests that corn DDGS from the traditional ethanol production process has similar ME as corn, but slightly lower NE. New fuel ethanol processes have been developed including pre-fermentation fractionation of the corn kernel as well as new approaches to conversion of starch to free sugars that rely less on heat and more on enzymatic conversion. These new processes produce different co-products including high protein DDG and corn germ, which contain more ME and NE compared with corn.

Corn gluten feed and corn gluten meal are co-products of the corn wet-milling industry. Corn gluten feed contains more fiber, but less starch and fat than corn, resulting in ME and NE values that are 76 and 62% of that in corn. Corn gluten meal is a high protein feedstuff that has more ME and less NE compared to corn. Many high protein feed ingredients have a lower NE:ME ratio than corn. For more information see PIG Factsheet 07-02-03 (Understanding Swine Nutrient Recommendations).

Wheat milling co-products include bran and middlings. As the name implies, wheat bran is a high fibrous feedstuff and has 71 and 61% of the ME and NE, respectively. Wheat middlings consist of fine particles of wheat bran, wheat shorts, wheat germ, wheat flour, and the offal from the milling process with fiber and fat, but less starch compared with wheat. The ME and NE in wheat middlings are 88 and 83% of the value for wheat.

Dried bakery waste is a mixture of bread, cookies, cake, crackers, flours, and doughs. This product contains less fiber and starch, but more fat than corn resulting in ME and NE values greater than for corn.

Protein sources: Protein sources are used to compliment cereal grains to meet the amino acids needs of the pig. The energy contribution from protein sources in the diet can be significant. The ME of many protein sources is similar to corn; however, the NE of protein sources is often lower compared than in corn. The NE of these feed ingredients provides a better estimate of the "true" energy available to the pig from protein sources than ME values do. Thus, diets containing high-protein feed ingredients are more accurately formulated if based on NE values. For more information see PIG Factsheet 07-02-03 (Understanding Swine Nutrient Recommendations).

Plant protein sources: Soybean meal is the most widely used protein source in the U.S. The ME of soybean meal (47.5 and 46.5% CP) is similar to the ME value for corn. Soybean meal (44% CP) contains 93% of the ME of corn because of the inclusion of hulls to this product. However, for all types of soybean meal the NE is much lower than the NE of corn, averaging 74% of the NE in corn. Further refinement of soybean meal to soy protein concentrate and soy protein isolate increases the ME and NE. On the other hand, whole full-fat soybeans contain more ME and approximately the same NE as corn when heat processed to inactivate anti-nutritional factors. Other protein sources, such as canola meal, flaxseed meal, and dehulled sunflower meal contain approximately 78 and 60% of the ME and NE, respectively, compared to corn.

Animal protein sources: The ME and NE concentration of blood products used in swine diets varies considerably. Flash-dried blood meal contains the lowest amount of ME and NE, while spray-dried blood meal contains 86 and 59% of the ME and NE in corn. Spray-dried plasma and blood cells contain more ME than corn, but less NE (93%) than corn. The reason for the lower NE values in blood products is the absence of starch and the low fat concentration in these feed ingredients. On the other hand, spray-dried egg contains greater ME and NE than corn due to the high fat concentration (28%) of this product. Fish meal contains similar ME as corn, but the meat protein products contain less ME than corn. The NE:ME ratio of these ingredients averages 0.65 due to the high protein concentration and the absence of starch in these feed ingredients.

Milk products (lactose, skim milk, dried whey) have ME values similar to that for corn, but they have slightly greater NE values than corn. Also, the NE:ME ratio for lactose and dried whey average approximately 0.92 which is higher than for corn. Further processing of whey to whey permeate or whey protein concentrate increases the ME; however, the NE decreases to approximately 70% of ME.

Fiber sources: Some feed ingredients have high concentrations of fiber and thus relatively low concentrations of ME and NE. Inclusion of high fiber ingredients in growing-finishing pig diets will decrease efficiency of feed utilization and may decrease rate of gain.. As the pig matures, greater amounts of high fiber ingredients can be fed, especially to gestating sows due to increasing intestinal tract capacity and greater fermentation in the hind gut. Maximum inclusion levels of high fiber ingredients, as well as all other feed ingredients, are shown in PIG Factsheet 07-07-09 (Composition of Feed Ingredients for Swine).

Examples of high fiber ingredients used in swine diets include alfalfa meal, soybean hulls, wheat bran, and beet pulp. These ingredients have low ME concentrations and the NE ranges from approximately 53 to 66% of ME. These ingredients may contain only 33 to 56% of the NE in corn.

Fat and Oils: Fats and oils contain approximately 2.25 times more ME than corn. Fats and oils used in swine diets include animal fats (beef tallow, choice white grease, poultry fat, and fish oil) and vegetable oils (corn, soybean, canola, restaurant grease). Performance responses of growing/finishing pigs fed supplemental fat (0 to 5%) are typically decreased feed intake and increased feed efficiency. Higher additions of fat to the diet may further improve feed efficiency, but carcass fatness may increase if limiting amino acid to energy ratios are not maintained when fat is added. While pigs will consume very high fat diets, there is a limitation to the amount of fat added without compromising feed flow characteristics. Addition of fat to late gestation sow diets reportedly increases birth weight and survival of newborn pigs. Inclusion of fat in lactation diets increase ME and NE intake of the sow, milk fat concentration, and pig weaning weights. Other benefits of fat inclusion in swine diets include a decrease in the dustiness of feed, an improvement in air quality in swine buildings, and reduced wear on feed processing equipment.

Dietary additions of fat in hot environments reduce the heat increment associated with fat digestion and metabolism compared with digestion of carbohydrates and protein. This reduces the heat burden on pigs during times of elevated temperatures and often results in greater feed intake and improved rates of weight gain.

While addition of fat to swine diets generally will decrease voluntary feed intake, the requirements for other nutrients by the pig remain relatively constant per unit of energy consumed. Therefore, to maintain performance when fat is added to the diet, the concentrations of other nutrients should be increased to account for the decrease in feed intake. Formulation of diets on a g of nutrient/Mcal basis will account for changes in dietary energy concentration.

Table 1. Energy concentration (ME, NE) and the NE:ME ratio for feed ingredients commonly included in swine diets[ab].						
Feedstuff	**DM, %**	**ME, kcal/lb**	**Ref. for ME**	**NE, kcal/lb**	**Ref. for NE**	**NE:ME**
Cereal Grains						
Corn						
Grain, yellow dent	89	1555	1	1203	3	0.77
Grain, high nutrient	87	1662	5, 6	1273	2 (NE1)	0.77
Grain, high oil	87	1629	7	1291	2 (NE1)	0.79
Grain, low-phytate	88	1629	8, 9	1286	2 (NE1)	0.79
Barley, two row	89	1322	1	1034	3	0.78
Oats						
Grain	89	1232	1	861	3	0.70
Groat	90	1575	1	1218	2 (NE1)	0.77
Millet, proso	90	1340	1	1004	2 (NE1)	0.75
Rye	88	1390	1	1070	3	0.77
Sorghum, grain (milo)	89	1518	1	1187	3	0.78
Triticale	90	1445	1	1122	3	0.78
Wheat						
Grain, hard red winter	88	1459	1	1114	3	0.76
Cereal grain Co-products						
Corn						
Distillers dried grains w/solubles (DDGS)	88	1552	5, 10, 11	1076	2 (NE1)	0.69
Distillers dried grains-high protein	90	1876	12, 13	1252	2 (NE1)	0.67
Germ	91	1618	12, 13	1259	2 (NE1)	0.78
Gluten feed	90	1184	1	740	3	0.63
Gluten meal, 60% CP	90	1741	1	1122	2 (NE1)	0.64
Hominy feed	90	1459	1	1104	2 (NE1)	0.76
Glycerol, crude (86.96 % glycerol)	91	1458	14	---		
Wheat						
Bran	89	1034	1	679	3	0.66
Middlings, <9.5% fiber	89	1375	1	993	2 (NE1)	0.72
Bakery waste, dehydrated	91	1682	1	1349	2 (NE1)	0.80
Fats/Oils[c]						
Animal fats						
Beef tallow	99	3491	1	3142	4	0.90
Choice white grease	99	3616	1	3254	4	0.90
Poultry fat	99	3718	1	3346	4	0.90
Fish oils						
Herring	99	3786	1	3407	4	0.90
Menhaden	99	3698	1	3328	4	0.90
Vegetable oils						
Canola	100	3823	1	3441	4	0.90
Corn	100	3820	1	3438	4	0.90
Restaurant grease	98	3730	1	3357	4	0.90
Soybean	100	3818	1	3436	4	0.90

Table 1. Energy concentration (ME, NE) and the NE:ME ratio for feed ingredients commonly included in swine diets[ab]. *(continued)*						
Feedstuff	**DM, %**	**ME, kcal/lb**	**Ref. for ME**	**NE, kcal/lb**	**Ref. for NE**	**NE:ME**
Plant Proteins						
Canola meal	90	1200	1	687	3	0.57
Flax (linseed) meal, sol. extr.	90	1229	1	793	3	0.65
Peas	88	1500	15	1082	2 (NE1)	0.72
Soybean						
Meal, dehulled, 47.5% CP	90	1536	1	907	3	0.59
Meal, dehulled, 46.5% CP	90	1517d	1	894	3d	0.59
Meal, 44% CP	89	1445	1	881	3	0.61
Meal, fermented	91	1520	16	938	2 (NE2)	0.62
Protein concentrate	90	1591	1	969	2 (NE2)	0.61
Protein isolate	92	1618	1	922	2 (NE2)	0.57
Seeds, heat processed	90	1677	1	1162	3	0.69
Sunflower meal, 42% CP	93	1243	1	732	2 (NE1)	0.59
Animal Proteins						
Blood						
Cells, spray-dried	92	1900	17	1115	2 (NE2)	0.59
Meal, flash-dried	92	886	1	386	2 (NE2)	0.44
Meal, spray-dried	93	1338	1	710	2 (NE2)	0.53
Plasma protein, spray-dried	91	1809	18	1094	2 (NE2)	0.60
Egg, spray-dried	---	2285	19	1696	2 (NE1)	0.74
Fish meal, menhaden	92	1527	1	994	3	0.65
Lactose	96	1561	1	1447	4	0.93
Meat and bone meal (≥ 4.0% P)	96	1249	20, 21	798	2 (NE1)	0.64
Meat meal (< 4% P)	96	1328	20, 21	842	2 (NE1)	0.63
Skim milk, dried	96	1689	1	1232	3	0.73
Whey						
Dried	96	1450	1	1299	3	0.90
Permeate	96	1500	1	1080	2 (NE1)	0.72
Protein concentrate, 78%CP	94	1978	22	1290	2 (NE1)	0.65
Fiber sources						
Alfalfa meal, dehydrated	92	750	1	398	3	0.53
Soybean hulls	89	848	3	453	3	0.53
Beet pulp	91	1134	1	671	3	0.59

[a]ME from swine NRC (1998 [1]) unless otherwise noted under Ref. for ME.
[b]NE values from Noblet [2] equation 1 (NE1) or equation 2 (NE2) or from EvaPig [3] unless otherwise noted under Ref. for NE.
[c]NE of fat/oil sources assumed to be 90% of the ME [4].
[d]Based on a blend of soybean meal (47.5% CP) and soybean hulls.

Summary

Energy is the primary cost component of swine diets. In typical US swine diets, cereal grains provide most of the energy; however, differences exist in energy concentrations among cereal grains that can impact diet formulation. Cereal grain co-products may have ME values similar to corn, but due to higher fiber concentration, these products have lower NE values than corn. Fiber sources generally have lower ME and NE values than corn, but their value increases with the age of the pig. Fats and oils are excellent energy sources in swine diets and may be used to enhance performance when cost effective. Protein sources also provide a significant amount of energy in swine diets. While protein sources may have a similar ME as corn, their NE concentration is lower than in cereal grains due to higher protein concentrations. Accurate estimates of the energy content of feed ingredients along with an understanding the energy contribution of the various feed ingredients in swine diets can minimize diets costs. Formulation of diets on a Net Energy basis has the potential to further improve the effectiveness of diet formulation.

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Frequently Asked Questions

Can other cereal grains replace corn in the diet?

Yes, other cereal grains can replace corn in the diet. Ideally diets should be reformulated when corn is replaced. Both sorghum and wheat are effective replacements for corn in the diet of growing-finishing pigs. Sorghum contains slightly less energy than corn and if substituted for corn on a pound for pound basis feed efficiency will be slightly depressed . Wheat is an excellent replacement for corn in the diet, but often is not competitively priced compared with corn and sorghum. Other cereal grains such as barley, oats, and rye contain less energy than corn due to the higher fiber concentration. Because all other cereal grains have lower energy density than corn, substitution of these cereal grains for corn in the diet will decrease energy concentration of the diet and affect pig performance. Decisions concerning the replacement of corn with other cereal grains in the diet need to account for not only the energy of the grain, but also the contributions the grain source makes to the amino acid and phosphorus concentration of the diet. It is important to consider maximum inclusion levels (see PIG factsheet 07-07-09 (Composition of Feed Ingredients for Swine)) and nutrient composition of alternative cereal grain sources when formulating diets for swine to limit negative effects on growth performance.

Does inclusion of DDGS or other corn co-products affect the energy concentration of the diet?

Recent research suggests that the ME of DDGS from traditional ethanol production process is similar to corn. Thus, inclusion of DDGS in the diet does not lower ME concentration of diet. However, the ME of high-protein DDG and corn germ from newer ethanol production processes is greater than that for corn; thus, inclusion of these co-products will increase the energy concentration of the diet and slightly decrease the NE of the diet.

Should fat be added to the diet?

Fat is an excellent energy source and contains at least 2.25 times more ME than corn. Adding to diets will improve feed efficiency and possibly daily gain. Addition of fat to diets fed during lactation also improves energy intake of the sow, the energy concentration of the milk, and litter weaning weights. Additions of fat above 5% of the diet further improves feed efficiency, but may result in slight increases in backfat and reduced physical handling properties of the feed. Additions of 6 to 8% are often used in the U.S. The decision to add fat to the diet is a purely an economical one. Fat sources are always more expensive per pound than the cereal grains and the decision of how to use fat in the diet can be made by evaluating the ratio of fat cost to corn cost. The increase in cost of the diet must be offset by improvements in pig performance. When the ratio of dry matter fat cost to dry matter corn cost trends below the historical average, fat inclusion is favored. When it trends above the historical ratio, fat inclusion is less favored. Fat inclusion in diets offers some non-nutritive advantages as well, such as a reduction in dustiness of the feed, improvement in building air quality, and reduced wear on feed processing equipment.

Should the levels of other nutrients in the diet be adjusted when adding fat to the diet?

Yes. When fat is added to the diet, energy concentration increases and feed intake decreases unless there are other constraints on ad libitum feed intake. The decrease in feed intake may result in inadequate intake of other nutrients and result in performance level below expectation. As a result, the concentrations of amino acids, Ca, and P need to be increased in a diet containing fat. Diets should be formulated to constant nutrient:energy ratios , which will then account for changes in dietary energy density and should reduce risk of nutrient deficiencies when fat is added to diets. Recommended lysine:energy ratios (g/Mcal) for various classes of swine are shown in PIG Factsheet 07-02-09 (Nutrient Recommendation Tables from the NSNG).

Can high-fiber feed ingredients be included in swine diets?

Yes, but the inclusion of these ingredients should be managed to assure maximum efficiency of feed utilization. High-fiber feed ingredients are better utilized as the pig matures. Gestating sows can tolerate more dietary fiber than other classes of swine. In younger pigs, inclusion of high-fiber feed ingredients can limit growth performance. Maximum inclusion levels of high-fiber feed ingredients (as well as other ingredients) are presented in PIG Factsheet 07-07-09 (Composition of Feed Ingredients for Swine).