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ENERGY EVALUATION OF PROTEIN SOURCES FOR YOUNG SWINE.

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Energy evaluation of protein sources

for young swine

by

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INTRODUCTION

The cost of feed for swine represents approximately 70% of the total cost of producing edible pork, while the cost of the energy component of the ration is by far the greatest. With the continued increase in the price of feed ingredients, producers cannot afford to feed any nutrient in excessive amount. In the formulation of swine diet, the energy system is considered best of all the feeding standards, and the net energy (NE) system should be the most accurate basis for predicting energy actually available to the animal, because heat increment is considered as well as urine and fecal losses.

Very few studies have reported values for energy utilization of protein sources for young swine. The values reported in NRC (1973) nutrient requirements publication for swine were based on the calculations of energy values from digestible nutrients. The objectives of the present study were to determine the digestible energy (DE), the metabolizable energy (ME) and the net energy (NE) values of three protein sources, meat and bone meal, dried skimmed milk and peanut meal, used in formulation of rations for young swine.

LITERATURE REVIEW

Historical Background

One of the earliest and great contributors in the field of nutrition and calorimetry was Antonie Lavoisier (Mckie, 1952; Swift and French, 1954). Early in the 18th century, Lavoisier concluded from his experiments that "the maintenance of the animal body at constant temperature above that of its surroundings was due to the release of heat or 'matter of life,' comparable to that produced from a burning candle" (Mckie, 1952). Since the design of the first ice calorimeter by Lavoisier and Laplace almost two centuries ago, many significant advancements and improvements in calorimetry and animal energetics have been made. Most of the early calorimeters were designed for work with men and large farm animals. Atwater and Benedict (1905) reported the development of a respiratory calorimeter for the direct determination of oxygen consumption and carbon dioxide production in experiments done with man.

Calorimetric Methods

Heat production which results from oxidation of food in farm animals has been measured either by direct or indirect calorimetry. In direct calorimetry, animal is placed in a double walled chamber with inner copper wall. An example of this is the adiabatic heat flow calorimeter built by Armsby and Fries in 1903 (Blaxter, 1962). Another method of direct calorimetry is the gradient layer calorimeter developed by Benzinger in 1949. According to Blaxter (1962), this was based on the principle first employed by Richet and Rubner in 1889 for animal calorimeter. In the modern gradient layer calorimeter, gradient layer of copper and constantan are woven through an insulating layer. The gradient layer lining ensures that the total heat emitted from a source in the cavity is recorded regardless of location and size. The use of direct calorimetry, although accurate, is very laborious and expensive method of evaluating energy values of feeds.

The indirect calorimetry method is based on amount of oxygen consumed and amounts of carbon dioxide and nitrogen excreted by the animal. One method of indirect calorimetry is the respiratory quotient (RQ), in which the ratio of carbon dioxide produced to oxygen consumed is used as an index of metabolic process. Another method, carbon:nitrogen (C:N) balance is based on the premise that if heat of combustion of nutrients absorbed by the animal is known, and the heat of combustion of body constituents which are stored or lost is estimated, then the heat of the overall reaction is obtained by difference. The C:N balance is one of the oldest indirect methods used as far back as 1886 by Pettenkofer and Voit (Blaxter, 1962). Two types of apparatuses have been employed in indirect calorimetry methods, and these are open circuit respiration apparatus and closed circuit respiration apparatus.

In the open circuit respiration apparatus, outdoor air is let into the chamber and changes in carbon dioxide (CO_2) and methane (CH_4) concentrations are measured. Samples of air going in and out of the chamber are taken at different intervals and oxygen consumption computed. With the closed circuit respiration apparatus, air is circulated continuously through absorbents that remove CO_2 and water vapor. Air freed of these gases is returned to the chamber and oxygen is admitted into the chamber with fall in pressure. Oxygen consumption is measured directly, and the absorbents are weighed to determine CO_2 produced.

Another method of indirect calorimetry is the comparative slaughter technique. The method measures energy gain made by a group of animals fed the experimental diet for a given period of time. The energy composition of the experimental group is compared to the energy composition of an initial slaughter group.

Development of Feeding Standards

As early as 1910, Kellner reported calculations of the net energy values of diets obtained by direct and indirect calorimetry methods. Armsby and Fries (1915) reported the net energy values of feedstuffs for cattle based on Kellner's method of net energy evaluation. Forbes and Kriss (1925) reported net energy values of feedstuffs for cattle obtained from direct respiration calorimetry studies.

Atwater (1890) proposed the use of Rubner's factors for the development of feeding standards for cattle. These energy values, later known as Atwater's "available fuel values," were: 4.1 kcal/gram carbohydrate, 4.1 kcal/gram protein and 9.3 kcal/gram fat.

Kellner (1910) developed a table of starch equivalent values for a number of feedstuffs based on the digestible nutrients in the feedstuffs. This system expresses the food value of feedstuffs compared to starch. However, Kellner (1910) reported that "it would not be correct to include only nitrogen-free substances in the starch equivalent, for in very many cases the greater part of the food protein is not used for the formation of flesh, but utilized in the same way as the nitrogen-free nutrients." The Scandinavian feed unit, which used barley as the reference feedstuff or standard, is similar to starch equivalent value.

The Wolff standards as modified by Lehmann in 1897 appeared in American literature in 1897 (Maynard, 1953). Hills et al. (1910) and Woll and Humphrey (1910) both modified the Wolff-Lehmann standards, which later came to be known as the "total digestible nutrients" (TDN) standard. The TDN standard then became the accepted standard of formulating animal diets in the United States early in the 20th century. TDN is calculated as follows:

Digestible protein + digestible carbohydrate

+ digestible fat x (2.25)

Maynard (1953) reported that the TDN formula was intended to summate the digestible nutrients on an equivalent carbohydrate basis in terms of gross caloric value. He observed that "TDN does not mean exactly what the term implies, because the long used method of calculating this takes account of certain urinary losses as well as undigested nutrients." But the term TDN implies that digestion losses only are accounted for, and Maynard (1953) proposed the use of the following formula for TDN:

Digestible protein (x 1.36) + digestible carbohydrate

+ digestible fat (x 2.25) = TDN

Several limitations have been recognized in the use of TDN system as the feeding standard. One limitation of TDN is over estimation of the productive value of forages, particularly poor quality forages, in relation to concentrate feeds. TDN is an ineffective system for substituting different feeds in livestock diets. The TDN system ignores variation among feeds in energy loss via urine, methane and heat production. The TDN system is based on physiological fuel values for humans and dogs which may not be applicable to farm animals.

Mitchell (1942) advocated the use of metabolizable energy (ME) as a measurement of the value of ration in satisfying the energy requirements of the animal rather than TDN, based on his digestibility trials. Later Lofgreen (1951) suggested the use of DE in evaluation of feeds because DE is not affected by the amount of water and ash in the feed while TDN would be affected. Maynard (1953) reported that caloric value of 4.38 kcal per gram TDN appeared to be more realistic than the use of Atwater's physiological fuel value of 4 kcal per gram carbohydrate which gives a conversion factor of 1814 kcal per pound TDN. Swift (1957) after examining 312 individual values determined a value of 1999.4 kcal per pound of TDN instead of 1814 kcal per pound of TDN (4 kcal/gram x 453.6 grams/lb = 1814). He suggested the use of 2000 kcal/lb to express TDN on a caloric basis. Crampton et al. (1957) conducted studies to further elucidate the quantitative relations between TDN and digestible calories in swine rations and reported a value of 4.5 kcal/gram TDN which agreed with the recommendation of Swift (1957) of 2000 kcal per pound TDN.

In November, 1958, the National Research Council (NRC) committee on Animal Nutrition passed a resolution to use the caloric or energy system along with the TDN system to describe the energy values of feeds and nutrient requirements of farm animals.

The Energy System

The conventional energy utilization scheme as outlined by Harris (1963, 1966) is outlined in Figure 1.

Gross energy (GE) is the amount of heat released when a substance is completely oxidized in a bomb calorimeter containing about 25 atmospheres

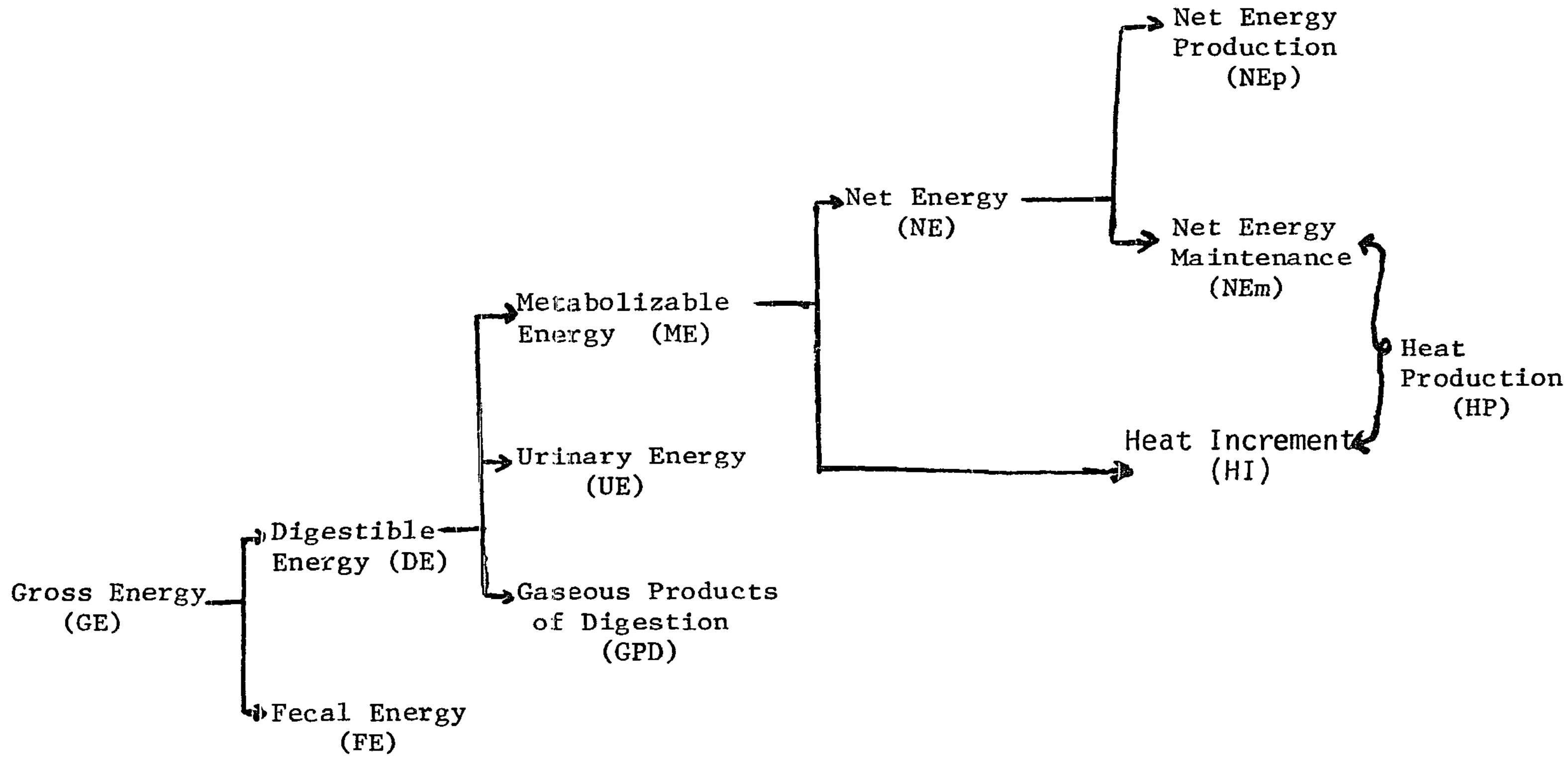


Figure 1. Energy utilization scheme

of oxygen. It is measured in calories and used to compute energy consumption for a given period.

Digestible energy (DE) is gross energy consumed (GE_i) minus fecal energy (FE). This value represents the apparent DE because the fecal energy includes the energy of undigested food and the metabolic fractions of feces. The metabolic fractions are composed of body excretions into the digestive tract such as juices and enzymes secreted into the gastrointestinal (G.I.) tract, abrasions from walls of the G.I. tract, cells sloughed from the walls of G.I. tract and bacteria and protozoa.

Metabolizable energy (ME) is the DE minus urinary energy (UE) and energy of the gaseous products of digestion. The gaseous products of digestion are a very negligible portion of energy loss in non-ruminants and are often ignored; whereas, in ruminants on full feed, methane loss could be as high as 7% of the total energy intake or more. Gaseous losses from feed are related to the undigested portion of the feed, and in ruminants, gaseous losses can be calculated based on dietary carbohydrate content.

The nitrogen-corrected metabolizable energy (MEn) is the ME corrected for nitrogen retained or lost from the body. Metta and Mitchell (1954) reported that it is necessary to correct ME for protein stored or lost from the body, because protein stored has not been catabolized, while protein lost from the body originated from the tissues and not the feed consumed. Correction to nitrogen equilibrium is made because the animal does not completely oxidize protein but excretes nitrogenous products such as urea and creatinine. The product of the caloric value per gram urinary nitrogen multiplied by the nitrogen balance gives the correction factor added to ME if animal is in negative nitrogen balance or subtracted if the animal is in positive nitrogen balance.

Different values have been reported in the literature for the caloric value of urinary nitrogen and have been observed to vary depending on species used. Metta and Mitchell (1954), experimenting with rats, reported a value of 6.29 kcal/gram urinary nitrogen, while May and Nelson (1972) reported a value of 10.12 kcal/gram urinary nitrogen. Diggs et al. (1965) reported a value of 6.77 kcal/gram urinary nitrogen in experiments with pigs, and Morgan et al. (1975a) used a value of 9.17 kcal/gram urinary nitrogen to correct ME in experiments with pigs. However, most investigators have used Rubner's factor of 7.45 kcal/gram urinary nitrogen obtained in experiments with dogs.

The direct determination of the heat of combustion of urine in energy studies is tedious and time consuming, and several investigators have proposed different equations for predicting the caloric value of urinary nitrogen. Paladines et al. (1964) experimented with sheep and proposed a regression equation for predicting urinary energy from urinary nitrogen. Street et al. (1964) proposed a similar regression equation for estimating urinary energy from urine nitrogen for cattle.

The net energy (NE) is the difference between ME and heat increment (HI). The NE represents the portion of the GE which the animal utilizes for maintenance and production. The NE value of a feed is the net worth of the feed as all losses associated with digestion and metabolism have been duly accounted for. According to Harris (1966), HI is the increase in heat production following consumption of food when the animal is in a thermoneutral environment. It is composed of the heat of fermentation and nutrient metabolism. HI may be measured by feeding the animal at two levels of energy intake above maintenance and computing the difference in heat production (HP). Baldwin (1968) reported that HI reflects the energy expenditures required for the incorporation of foodstuffs into the product. HI is generally wasted except when the environmental temperature is below the critical temperature. Then, HI is used to keep the body warm and constitutes part of the net energy for maintenance (NEm).

The Net Energy Utilization

NE is usually reported as NE for maintenance (NEm), NE for production (NEp) or both (NE_{m+p}). The NEm is the portion of NE expended to keep the animal in energy equilibrium with no net gain or loss of energy. It consists of basal metabolism, energy of voluntary activity and energy to keep the body warm or cool. A producing animal may have a NE for maintenance different from that of a non-producing animal of the same weight. This is due to changes in amounts of hormones produced and to differences in voluntary activity (Harris, 1966). NEp is that portion of the NE available after the maintenance requirement had been satisfied and may be used for work, tissue gain (growth) or synthesis of milk, feathers or fur and fetal development.

Metabolizable energy can be considered as the sum of heat production (HP) and the net energy of production (NEp) (Lofgreen, 1971). In the process of utilization of ME, a portion of the energy is used for conversion or metabolism of the absorbed dietary components into tissue and is defined as heat increment (HI). Lofgreen (1971) said, "basic to an understanding of the separation of maintenance from production energy is the recognition that NE required for maintenance is measured as heat and NE for production is measured as energy appearing in the product." The whole acceptance of the NE system, therefore, rests on the ease with which heat production (HP) is measured. Heat production can be defined from the following sets of equations (Lofgreen, 1971):

$$NE = ME - HI \quad \text{---------} \; 1$$
$$NE = NEm + NEp \quad \text{---------} \; 2$$
$$NEm + NEp = ME - HI \quad \text{---------} \; 3$$
$$NEm = Hb + Ai \quad \text{---------} \; 4$$

By substituting for NEm in equation 3,

$$Hb + Ai + NEp = ME - HI \quad \text{---------} \; 5 \qquad \text{THEREFORE}$$
$$Hb + Ai + HI = ME - NEp \quad \text{---------} \; 6$$
$$\text{But } HP = HI + Ai + Hb \quad \text{---------} \; 7$$

OR

$$HP = ME - NEp; \; ME = HP + NEp \quad \text{---------} \; 8$$

Where:

NE = Net energy
ME = Metabolizable energy
HI = Heat increment
NEm = Net energy for maintenance
NEp = Net energy for production
Hb = Basal heat production
Ai = Activity increment
HP = Total heat production, i.e., HI + Ai + Hb

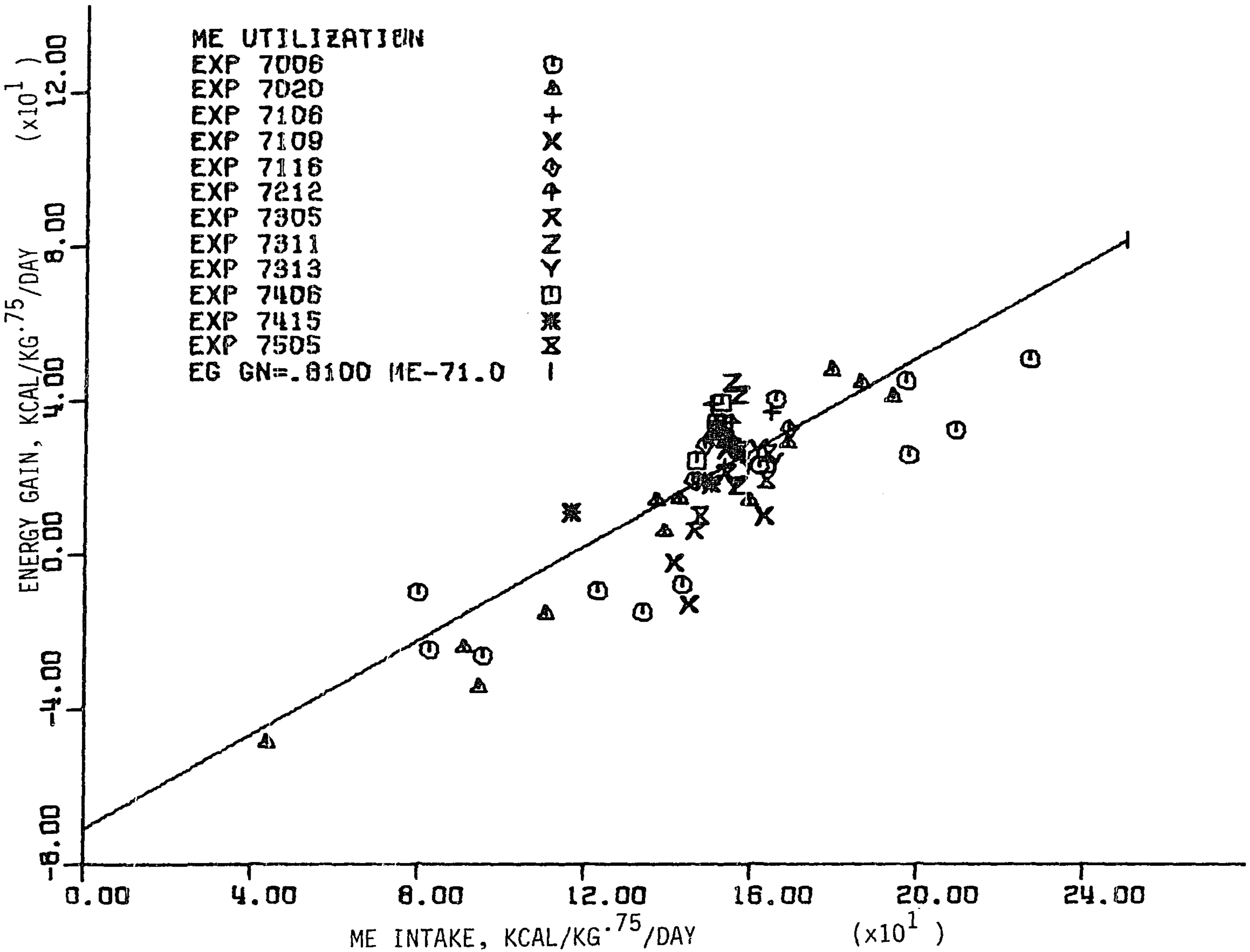
Evaluation of the utilization of ME of feed requires the measurement of HP or NEp. Heat production may be measured by direct or indirect calorimetry. NEp in growing animals may be measured as energy gain by carbon-nitrogen balance or comparative slaughter technique.

The comparative slaughter technique has been used to determine NE value of feeds in these and previous studies done with swine at this University (Ewan, 1976). One animal from each replication is slaughtered at the initiation of the experiment, and the body composition of the initial slaughter group compared to those of animals fed at different levels of experimental diets and slaughtered at the end of the trial. According to Lofgreen and Otagaki (1960), when a ration is fed at different levels above maintenance, net energy for production (NEp) of feed increment can be determined by the difference in energy retention between the lower and higher levels of feeding. The gain is attributed to the feed increment. The extrapolation of the regression between positive energy balances and ME intake to zero gives the theoretical minimal energy balance for maintenance (Reid, 1974). The NEm for pigs in these experiments have been derived from data accumulated from balance studies with 5 to 10 kg pigs at this University. By regression of ME intake on energy gain, Figure 2, the intercept at zero ME intake was 71.0 kcal/$W^{.75}$ kg and estimates the NEm for 5 to 10 kg pigs (Ewan, 1975). The $W^{.75}$ is the metabolic body size.

Kleiber (1947, 1961) and Brody (1974) reported that metabolic body size is a useful index of expressing levels of feed intake and animal production. Basal metabolism was observed to vary directly with metabolically effective body weight, W^{b}. The value b represents the slope of the line when basal metabolic rate (BMR) versus body weight in kilograms is plotted on logarithmic paper. Kleiber (1947) observed a linear correlation between the logarithm of the metabolic rate and logarithm of body weight, which indicated that metabolic rate is proportional to a "given power function" of body weight, e.g., $W^{.75}$. Values for NEm and energy gain in the present studies are reported based on metabolic body size, $W^{.75}$.

The determination of body composition is a problem in the determination of NE values, particularly for larger animal species. Several indirect methods of determining body composition utilize the inverse

Figure 2. Relationship of ME intake and energy gain


ME UTILIZATION
EXP 7006
EXP 7020
EXP 7106
EXP 7109
EXP 7116
EXP 7212
EXP 7305
EXP 7311
EXP 7313
EXP 7406
EXP 7415
EXP 7505
EG GN=.8100 ME-71.0
ENERGY GAIN, KCAL/KG.75/DAY
(x10^1)
12.00
8.00
4.00
0.00
-4.00
-8.00
0.00
4.00
8.00
12.00
16.00
20.00
24.00
ME INTAKE, KCAL/KG.75/DAY
(x10^1)

relationship between body fat and body water. The water content of the body has been estimated using antipyrine, deuterium or tritium. Other methods have employed the relationship between specific gravity in air or water and the carcass fat, water, protein and ash. However, the various indirect methods of determining body composition (Rathbun and Pace, 1945; Kraybill et al., 1951; Liuzzo et al., 1958; Diggs et al., 1965; Lofgreen and Otagaki, 1960) have one thing in common: they are not as accurate as the direct method of determining body composition by complete chemical analysis.

Energy Evaluation of Feeds

Several early studies have determined the caloric values of feeds for ruminants (Armsby and Fries, 1915; Forbes and Kriss, 1925; Fraps, 1931; Kriss, 1931), but very few studies have been done with pigs (Mitchell and Hamilton, 1933; Garrigus and Mitchell, 1935; Fraps, 1932).

According to Martin and Blaxter (1961), the utilization of energy of protein in meeting the maintenance needs had been measured with dogs in calorimetric experiments by Rubner in 1902 and Lusk in 1931. The ME and productive energy (NE) values were also reported for a number of feedstuffs in experiments done with chicks (Hill and Anderson, 1958; Hill and Renner, 1960; Potter and Matterson, 1960).

However, there was a time lag in investigation of the utilization of energy of feeds by swine from the time of Garrigus and Mitchell (1935) until the early 1960's. Prior to the reports of Tollett (1961) and Diggs et al. (1965), most studies with swine concentrated on effects of fiber on feed and energy utilization. The utilization of energy of feeds by swine have been reviewed by Young (1972) and Ewan (1976) and these reports contain DE and ME values for protein sources commonly used in the formulation of swine diets.

Diggs et al. (1965) reported the DE and ME values for tankage, meat and bone scraps and menhaden fish meal in experiments with swine. They reported that ME was 81.5% of DE for these high protein feeds. Later, Saben et al. (1971a) evaluated samples of rapeseed and soybean meal as energy sources for growing pigs, and May and Bell (1971) reported the DE and ME values for a number of feed ingredients fed to pigs.

Most of the early studies and some of the most recent studies aimed at evaluating individual feedstuffs have used either of two methods, "substitution method" or "addition method." In the "addition method," the test ingredient (protein or energy source) is fed with a nutritionally adequate basal diet; while with the "substitution method," the test ingredient replaces a certain portion of the basal diet or replaces protein of another ingredient in the basal diet. It is not uncommon to find test diets with extremely high protein content, and oftentimes in trials designed to evaluate energy of protein sources, one finds more than one protein source in the basal diet.

May and Bell (1971), in experiments with growing pigs, formulated two basal diets of 10 and 20% crude protein content, respectively, to which two levels of the test ingredients were added. They observed significant differences between rations for digestibility of protein and energy, as well as DE and ME contents of the feeds. A highly significant correlation ($r = -0.96$, $P<.01$) was observed between ME:DE and dietary protein level.

The approach in the present studies was formulation of a basal diet where corn, soybean oil and the protein source being evaluated served as the sole contributors of energy.

EXPERIMENTAL PROCEDURE

Objectives

Three trials were conducted to determine the DE, ME and NE values of three protein sources, meat and bone meal, dried skimmed milk and peanut meal in the diets of young swine.

Experimental Design

The trials were conducted at the Swine Nutrition Research Farm of Iowa State University, Ames, Iowa, and the research data are on file as experiments 7610, 7619 and 7711. The experiments were conducted in Unit F equipped with twelve metabolism cages arranged in two rows, and the average temperature of the unit was 26°C.

The experimental animals (table 1) were crossbred barrows and gilts (Yorkshire x Landrace). In each trial, sixteen pigs were randomly allotted from litter outcome groups to four replications of four pens each and treatments were randomly allotted to pens within each replicate.

All pigs were fed the experimental diet for a seven-day adjustment period. Each basal diet was formulated with corn, soybean oil and the test protein source or ingredient as the sole contributors of energy in the diet (table 2). This was formulated to supply the nutrient requirements of young pigs as contained in the NRC (1973) recommendations for swine. The basal diet was fed to all pigs at 3% of body weight during the seven-day adjustment period.

The experimental treatments were: pigs fed the basal diet fed at 3% (1), 4% (2) or 5% (3) of body weight daily and pigs slaughtered initially (4). Refused feed was collected and pooled for each seven-day period, oven-dried

Table 1. Average initial age and weight

Experiment number	Average age (days)	Average initial weight (kg)
7610	24.0	4.50
7619	24.0	5.45
7711	24.0	5.80

Table 2. Composition of basal diets

Ingredients	Exp. 7610 %	Exp. 7619 %	Exp. 7711 %
Ground yellow corn	51.76	25.41	43.77
Meat and bone meal	43.54	--	--
Dried skimmed milk	--	69.89	--
Peanut meal, m-exd.	--	--	49.13
Soybean oil	3.00	3.00	3.00
Vitamin - additive premix[a]	1.20	1.20	1.20
Iodized salt	.45	.45	.45
Trace mineral mix (35-c-95)[b]	.05	.05	.05
Dicalcium phosphate	--	--	2.40
Total	100.00	100.00	100.00

[a]Contributed the following per kg of diet: 2010 I.U. vit. A; 243 I.U. vit. D_3; 386 mg riboflavin; 11.88 mg pantothenic acid; 27.28 mg niacin; 210 mg choline; 24.85 mcg vit. B_{12}; 600 mg vit. K; 60 I.U. vit. E.

[b]Contributed the following per kg of diet: 100 mg Zn; 50 mg Fe; 5.5 mg CU, 27.5 mg Mn, .75 mg I and .5 mg Co.

at about 52^{o}C, ground through a 10-mesh screen and retained for chemical analysis.

The pigs were weighed weekly, and the feeding levels were adjusted weekly. Each metabolism cage was equipped with an automatic waterer, and pigs were allowed water twice daily, one hour at each feeding. One half of the daily feed allotment was offered in the morning, and the other half offered approximately 12 hours later.

Sample Collection and Preparation

Total fecal and urine collections were made for four consecutive seven-day collection periods. Feces were placed in a jar with measured amount of 1N hydrochloric acid. At the end of each collection period, weights of feces in 1N hydrochloric acid were taken and recorded. Feces and hydrochloric acid were homogenized in a blender, and an aliquot was taken, adjusted to pH 3 with 5N sodium hydroxide or 5N hydrochloric acid and freeze dried.

Urine was filtered through the glass wool into bottles containing 25 ml concentrated hydrochloric acid and 25 ml of toluene. An aliquot of at least 10% of urine was retained and stored at -10^{o}C. The frozen urine sample was allowed to come to room temperature before pouring it into a separatory funnel to allow the toluene to separate. A sample of urine was retained for nitrogen determination. A refractometer was used to measure the specific gravity of urine, and the total solids were estimated from the specific gravity. An aliquot of urine was taken to provide about 10g of total solids and adjusted to a pH of 3 with 5N sodium hydroxide or 5N hydrochloric acid. Known amount of cellulose was added to provide about

25% of the total weight as solids. Urine containing the cellulose was homogenized, freeze-dried and stored for the determination of energy.

At the end of the adjustment period, one pig from each replicate was slaughtered. The live and empty body (animal after removal of intestinal fill) weights were recorded, and the empty body was stored at -10°C. At the end of the experiment, the pigs were killed by electric shock. The intestinal contents (fill) were removed and retained, and the empty body of the pig was stored at -10°C. A measured aliquot of fill was adjusted to pH 3 with 5N sodium hydroxide or 5N hydrochloric acid and freeze-dried.

The frozen empty bodies were sawed into small pieces and ground once through a 18mm die, once through a 10mm die and twice through a 4mm die in a Hobart grinder. About 300 g random sample of the carcass was retained. About 100 g carcass plus 100 ml distilled water were homogenized and freeze-dried. The freeze-dried carcass was ground through a 10-mesh screen for chemical analysis.

Chemical Analysis

Gross energy of the diets, test ingredient, urine, feces, intestinal fill, empty body and refused feed was determined by bomb calorimetry (Parr Instrument Co., 1970). Dry matter, ether extract and ash were determined according to the methods of A.O.A.C. (1970). Nitrogen was determined by the macro-Kjeldahl method (A.O.A.C., 1970).

Statistical Analysis

The data were analyzed statistically by the method of least squares (Harvey, 1960). The pig was considered as the experimental unit.

Calculation of Energy Values

The procedure followed in calculating the energy values of the test feed ingredients is presented in Appendix A.

RESULTS AND DISCUSSION

Experiment 7610

Average daily gain (ADG) and feed:gain (F:G) ratio were not affected by level of feeding of diet containing meat and bone meal (table 3). The ADG of pigs fed at 4% of body weight was greater than pigs fed at 3% of body weight but decreased slightly for pigs fed at 5% of body weight. Feed efficiency improved with increased feeding level and was best in pigs fed at 4% of body weight. Overall, the performances of pigs fed meat and bone meal diet was poor compared with pigs fed either dried skimmed milk diet or peanut meal diet. Babatunde et al. (1975) fed weanling pigs a diet containing about 20% meat and bone meal and reported depressed growth rate, feed consumption and feed efficiency. In this trial, the apparent digestion coefficients of dietary dry matter, nitrogen and energy were not significantly affected by the level of feeding (table 3).

Nitrogen balance increased linearly ($P<.05$) as level of feeding increased (table 3). Nitrogen balance was greatest in pigs fed at 4% of body weight daily, and these pigs retained more nitrogen than pigs fed at 5% of body weight. Net protein utilization (NPU) and biological value (BV) of the diets followed the same trend as the nitrogen balance, but differences between treatments were not significant. The observed trend for nitrogen balance could be due to the amount of feed consumed by pigs fed at 5% of body weight. Although pigs were fed at 3, 4 and 5% of body weights, respectively, the actual feed consumption averaged 2.83, 3.48, and 3.62% of body weight. At higher levels of feeding, more feed was consumed and more nitrogen retained, but the efficiency of nitrogen utilization was

Table 3. Experiment 7610. Effect of level of feeding a diet containing meat and bone meal on performance, digestion and metabolism[a]

Item	Units	Level of feeding[b] 3	4[c]	5	SE[d]
			Pig performance		
Daily gain	g	57	96	81	8.5
Feed:gain		2.9	2.0	2.5	.3
			Apparent digestion coefficient		
Dry matter	%	72.4	73.1	74.3	.7
Nitrogen	%	81.2	81.7	81.5	.6
Energy	%	80.0	80.4	80.7	.8
			Nitrogen metabolism		
Balance[e,f]	g	106.6	144.4	137.0	7.1
NPU[g]	%	51.7	56.0	54.1	2.7
BV[h]	%	63.8	68.5	66.4	3.4
			Energy metabolism		
DE	kcal/g	3.41	3.43	3.46	.04
ME	kcal/g	3.25	3.28	3.29	.04
ME[i]	% DE	95.4	95.7	95.1	.11
NE[j]	kcal/g	1.983	1.824	1.627	.06

[a]Averaged over the 28-day period.

[b]Basal diet fed at 3, 4 and 5% of body weight. Feeding levels were adjusted weekly.

[c]Mean of 3 replications. One pig died in the course of the experiment.

[d]Standard error for feeding levels 3 and 5. Standard error for feeding level 4 is 4/3 times the SE given above.

[e]Significant linear effect of level of feeding (P<.05).

[f]Nitrogen intake less fecal and urinary nitrogen for 28 days.

[g]Nitrogen balance as a percentage of nitrogen consumed.

[h]Nitrogen balance as a percentage of nitrogen consumed less fecal nitrogen.

[i]Significant quadratic effect of level of feeding (P<.05).

[j]Significant linear effect of level of feeding (P<.01).

unaffected. So, the differences in nitrogen balance were primarily because of differences in nitrogen intake.

The feed intake of pigs fed at higher levels of feeding was depressed probably because of amino acid imbalance. The meat and bone meal diet was marginal in tryptophan and provided a high level of phenylalanine (Appendix B). Amino acid imbalances have been reviewed by Harper et al. (1970). The authors observed that depressed feed intake is often preceded by changes in plasma amino acid concentrations and that feed intake of rats fed imbalanced diets was stimulated when they were continuously infused with the limiting amino acid. Mellinkoff (1957), as cited by Harper et al. (1970), proposed the aminostatic hypothesis of feed intake regulation in which changes in plasma amino acid pattern serve as signal to an appetite regulating center.

The DE and ME values of the diet increased as level of feeding increased (table 3), but the differences between treatments were not significant. The DE and ME of the diet averaged 3.43 and 3.27 kcal/g, respectively. A quadratic increase ($P<.05$) was observed for ME:DE of the diet, and an average value of 95.4% was observed. The NE of the diet decreased linearly ($P<.01$) as level of feeding increased (table 3). The NE of the diet should remain relatively constant at the different feeding levels if the diet is nutritionally balanced. Hamilton (1935) observed that the energy of a well-balanced ration is utilized with greater efficiency than the energy of a poorly balanced diet. Meat and bone meal was 43% of the diet fed to young pigs in this study. With this level of meat and bone meal in the diet, amino acid imbalance and mineral imbalance might have caused the NE to decrease as greater quantity of the diet was consumed.

With increased consumption of a diet of low biological value, more energy was expended in eliminating the excess nitrogen, and the cost of utilizing the available energy increased. Levels of meat and bone meal lower than the level fed in this study have produced poor performances of pigs (Peo and Hudman, 1962; Beames and Sewell, 1969; Beames and Daniels, 1970).

There were no significant differences observed between the experimental animals and the initial slaughter group for percentages of dry matter, water, ash or nitrogen (table 4). Empty body ether extract and energy of the experimental animals were significantly ($P<.01$) lower than the initial slaughter group. Pigs fed at 4% of body weight gained more nitrogen, ether extract, ash and energy daily than pigs fed at 3% of body weight or 5% of body weight (table 4); however, differences between treatments were not significant. Pigs fed at 3% or 5% of body weight daily had negative ether extract gain, indicating that these pigs were using body reserves to meet part of the daily energy requirements. The daily gain of nitrogen, ash and energy of pigs fed at 3% or 5% of body weight were similar.

The DE of meat and bone meal (table 5) was not significantly different among treatments. The DE of meat and bone meal was 3.09 kcal/g dry matter. Diggs et al. (1965) reported a DE value of 2.11 kcal/g dry matter for meat and bone meal. Morgan et al. (1975a) reported a value of 2.03 kcal/g dry matter as the DE of meat and bone meal in experiments with 45 to 70 kg pigs. Young et al. (1977) in experiments with pigs reported DE value of 2.40 kcal/g dry matter for meat and bone meal.

The DE:GE ratio decreased as feeding level increased (table 5) from 3% of body weight to 4% of body weight and decreased slightly at 5% of body weight. However, the differences were not significant. The DE:GE ratio

Table 4. Experiment 7610. Effect of level of feeding a diet containing meat and bone meal on body composition

Item	Unit	Level of feeding[a] 3	4[b]	5	IS[c]	SE[d]
			Body composition			
Dry matter	%	22.2	22.6	21.1	23.7	.8
Water	%	77.8	77.4	79.0	76.3	.8
Ash	%	3.7	3.6	3.6	3.4	.2
Nitrogen	%	2.6	2.6	2.4	2.4	.1
Ether extract[e]	%	3.1	3.4	2.8	5.4	.6
Energy[e]	kcal/g	1.21	1.18	1.14	1.44	.1
			Composition of daily gain			
Nitrogen	g	1.92	2.75	1.90	--	.3
Ether extract	g	-1.16	.99	-1.59	--	1.1
Energy	kcal	44.5	79.9	44.4	--	16.4
Ash	g	2.72	3.53	2.95	--	.6

[a]Basal diet fed at 3, 4 and 5% body weight. Feeding levels were adjusted weekly.

[b]Mean of 3 replications. One pig died in the course of the experiment.

[c]Initial slaughter group.

[d]Standard error for feeding levels 3 and 5. Standard error for feeding level 4 is 4/3 times the SE given above.

[e]Significant difference between initial and final composition (P<.01).

averaged 73.78% for meat and bone meal in this study and indicated that about 26% of the energy of meat and bone meal consumed by young pigs was lost in the feces. The poor digestibility of meat and bone meal may be because it contained undigested connective tissues. The DE:GE ratio for meat and bone meal is the lowest value so far obtained in energy studies with common feedstuffs for young pigs at this University.

Table 5. Experiment 7610. Energy availability and energy ratios of meat and bone meal

Item	Unit	Level of feeding[a] 3 Mean	SE[c]	4[b] Mean	SE[c]	5 Mean	SE[c]	Pooled Mean	SE[c]
				Air-dry basis					
DE	kcal/g	2.81	.076	2.85	.093	2.88	.076	2.85	.047
ME	kcal/g	2.61	.075	2.68	.091	2.66	.075	2.65	.045
NE[d]	kcal/g	1.19	.129	.82	.158	.37	.129	.79	.081
				Dry-matter basis[e]					
DE	kcal/g	3.05	.083	3.10	.101	3.12	.083	3.09	.051
ME	kcal/g	2.84	.081	2.91	.099	2.88	.081	2.88	.049
NE[d]	kcal/g	1.29	.140	.89	.172	.40	.140	.86	.088
				Energy ratios					
DE:GE	%	78.30	4.05	70.62	4.96	72.44	4.05	73.78	2.52
ME:DE[f]	%	92.95	.32	93.88	.40	92.32	.32	93.05	.20
NE:ME[d]	%	45.62	4.55	30.52	5.57	13.50	4.55	29.88	2.84
HI[d]	%	54.38	4.55	69.48	5.57	86.50	4.55	70.12	2.84

[a]Basal diet fed at 3, 4 and 5% of body weight. Feeding levels were adjusted weekly.

[b]Mean of 3 replications. One pig died during the course of the experiment.

[c]Standard error for feeding levels 3 and 5. Standard error for feeding level 4 is 4/3 times the SE given above.

[d]Significant linear effect of level of feeding (P<.01).

[e]Meat and bone meal contained 92.08% dry matter and 4.226 kcal per gram dry matter.

[f]Significant quadratic effect of level of feeding (P<.01).

The DE:GE value of 73.78% is, however, greater than average value of 45.3% that is found in the literature (Diggs *et al.*, 1965; Morgan *et al.*, 1975a; Young *et al.*, 1977). The GE content of the different meals is a factor that will affect DE value. Beames and Daniels (1970) fed meat and bone meal from two sources to pigs and observed different GE values for the two meals because of the bone and ether extract contents. Meat and bone meal used in our trial had a GE value of 4.23 kcal/g dry matter compared with the meat and bone meal used by Morgan et al. (1975a) with GE value of 3.73 kcal/g dry matter. Obviously, the DE obtained from these two samples of meat and bone meal will differ. An increase in the content of indigestible components of the meat and bone meal will lower the DE and the DE:GE values.

The ME of meat and bone meal was not different between feeding levels (table 5), and an average value of 2.88 kcal/g dry matter was observed in this study. Diggs et al. (1965) reported ME value of 1.76 kcal/g dry matter, and Morgan et al. (1975a) observed ME value of 1.68 kcal/g dry matter for meat and bone meal. Young et al. (1977), experimenting with pigs, reported a ME value of 2.17 kcal/g dry matter for meat and bone meal. Potter and Matterson (1960) in chicks trials reported ME value of 1.98 kcal/g dry matter, while Guirguis (1975) observed that ME of meat and bone meal averaged 2.55 kcal/g matter.

The ME:DE ratio (table 5), a measure of the efficiency of utilization of absorbed DE of meat and bone meal, increased quadratically ($P<.05$) as feeding level increased and was greatest for pigs fed at 4% of body weight. The average ME:DE ratio of 93.05% for meat and bone meal in this trial was greater than values that have been reported in literature. Diggs et al. (1965) observed ME:DE value of 83.0% for meat and bone meal. DE was more efficiently utilized in our study than had been reported in the literature. The high ME:DE ratio obtained for meat and bone meal in this study resulted in high ME value which far exceeded the literature values. Very little energy of meat and bone meal was lost in the urine.

Morgan et al. (1975a) reported the following relationship between ME and DE of feed ingredients: ME = DE (.997 - .0018% Crude Protein). They observed a reduction in ME:DE ratio of ingredients as level of crude protein increased. Using the above equation, a value of 2.81 kcal/g dry matter can be calculated for the ME of the meat and bone meal used in our study. The estimated value agrees well with the value of 2.88 obtained in this experiment.

One major difference in energy values obtained for meat and bone meal in this study and values reported in the literature is in experimental technique. Diggs et al. (1965) evaluated meat and bone meal by adding it to a basal diet containing 38% protein. The resulting diet had high protein content which might have decreased the ME value of meat and bone meal. The basal diet used in the present study contained about 28% crude protein on as fed basis and should give a higher ME value than was observed by Diggs et al. (1965). As the dietary protein content increases, more energy is required to eliminate the excess nitrogen. As Young et al. (1977) observed, differences in experimental techniques will affect energy values reported by different investigators. This is part of the difference in ME value observed for meat and bone meal in this study, and the values obtained by other investigators.

The NE of meat and bone meal decreased linearly (P<.01) as level of feeding increased (table 5). The average NE value of meat and bone meal observed in this study was .86 kcal/g dry matter. Because the NE of meat and bone meal decreased as the level of feeding increased, ME was not utilized with the same efficiency at the different levels of feeding. Amino acid or mineral imbalance may have contributed to the poor energy utilization.

NE:ME ratio (table 5), a measure of the efficiency of utilization of ME of meat and bone meal for energy gain by young pigs, decreased linearly (P<.01) as level of feeding increased. The HI, obtained by subtracting NE:ME value from 100, increased as feeding level increased (P<.01). Increased energy loss was encountered in the utilization of available energy of meat and bone meal for gain by young pigs as feeding level increased. This may be attributed in part to amino acid or mineral imbalance.

The works of Forbes and associates as cited by Morrison (1937) and Fraps (1937) showed that the NE of a nutritionally complete ration is markedly higher than the NE of an imbalanced ration. Mitchell and Hamilton (1940) observed that the utilization of ME of a ration depends on the nutrient balance, and Kleiber (1961) reported that the requirements for protein and most vitamins are directly related to energy metabolism. Amino acid and mineral imbalances of the meat and bone meal diet might have adversely affected the efficiency of utilization of available ME as the level of feeding increased.

Bloss et al. (1953), in experiments with weanling pigs, observed that meat and bone meal did not contain sufficient tryptophan to allow for normal growth. Batterham (1970b) fed maize-meat meal diet to growing pigs and reported that tryptophan is the first limiting amino acid and lysine the second limiting amino acid in maize-meat meal diet. Stockland et al. (1970) also observed that plasma levels of pigs fed meat and bone meal diets were deficient in isoleucine, methionine plus cystine, threonine, tryptophan and lysine. The calculated chemical analysis of basal diets (Appendix B) showed that the meat and bone meal diet was marginal in tryptophan and high in phenylalanine. While levels of some other amino acids appear adequate for young pigs, one can speculate that the diet was probably not balanced for amino acids.

Harper et al. (1970) observed that animals fed amino acid deficient diets had low concentrations of growth limiting amino acids and that the ratios of plasma indispensable amino acids to the limiting amino acids were elevated. The observed trend for the NE of meat and bone meal in the present study can be partly explained by the fact that, with increased consumption of the imbalanced diet, the concentrations of some indispensable or essential amino acids rose, producing an amino acid toxicity.

It can also be presumed that with amino acid imbalance, certain amino acids required for the synthesis of some proteins were lacking, and these protein types could not be synthesized. This resulted in the overload of the amino acids pools in pigs consuming higher levels of the diet containing meat and bone meal. More energy was required to rid the body of the excess amino acids, and HI from the utilization of ME for gain increased as feeding level increased.

Mineral imbalance is another factor that might have adversely affected the performance of pigs consuming meat and bone meal diet. The diet contained a calculated 4.99% calcium and 2.62% phosphorus (Appendix B). This calcium and phosphorus content is in excess of the requirement of .8% calcium and .6% phosphorus recommended by NRC (1973) for 5 to 10 kg pigs. Babatunde et al. (1975) reported that, with about 3.84% calcium and 1.93%

phosphorus in the diets of pigs, appetite could be reduced, and feed consumption significantly depressed. The high calcium and phosphorus level of the basal diet in the present experiment, probably combined with amino acid imbalance, caused poor feed intake at higher levels of feeding and the poor efficiency of utilization of ME for energy gain.

From the data reported in the present study, it can be concluded that the level of inclusion of meat and bone meal in the basal diet had profound effects on the utilization of ME of meat and bone meal. Guirguis (1976) reported that level of inclusion of test feedstuffs in a diet could possibly influence ME values. In this study, ME value of meat and bone meal was not influenced, but NE was adversely affected. Meat and bone meal, constituting 43% of the basal diet, resulted in nutrient imbalance which adversely affected the utilization of ME for NE gain. The results of this study demonstrate that DE and ME values are not good predictors of energy availability of diets or ingredients, but that the NE value serves as a good indicator of energy that is actually available to the animal.

Experiment 7619

The average daily gain of pigs increased linearly ($P<.01$) as level of feeding of diet containing dried skimmed milk increased (table 6). Differences among treatments for feed:gain ratio were not significant, but efficiency of feed utilization improved as level of feeding of the diet increased. The apparent digestion coefficients (ADC) of dry matter, nitrogen and energy were similar at all levels of feeding (table 6). The pigs were quite efficient in digesting dietary components of dry matter,

Table 6. Experiment 7619. Effect of level of feeding a diet containing dried skimmed milk on performance, digestion and metabolism[a]

Item	Units	Level of feeding[b] 3	4	5	SE[c]
			Pig performance		
Daily gain[d]	g	162	234	380	14.4
Feed:gain		1.32	1.28	1.14	.11
			Apparent digestion coefficient		
Dry matter	%	93.4	93.7	94.1	.4
Nitrogen	%	94.2	94.1	94.7	.4
Energy	%	94.9	95.0	95.3	.2
			Nitrogen metabolism		
Balance[d,e]	g	169.6	254.0	383.6	9.0
NPU[f]	%	66.1	68.0	70.4	2.6
BV[g]	%	70.1	72.3	74.4	2.6
			Energy metabolism		
DE	kcal/g	4.05	4.06	4.07	.01
ME	kcal/g	3.85	3.84	3.82	.03
ME	% DE	94.9	94.8	93.9	.6
NE	kcal/g	2.33	2.36	2.32	.1

[a]Averaged over the 28-day period.

[b]Basal diet fed at 3, 4 and 5% of body weight. Feeding levels were adjusted weekly.

[c]Standard error.

[d]Significant linear effect of level of feeding (P<.01).

[e]Nitrogen intake less fecal and urinary nitrogen for 28 days.

[f]Nitrogen balance as a percentage of nitrogen consumed.

[g]Nitrogen balance as a percentage of nitrogen consumed less fecal nitrogen.

nitrogen and energy, and the digestion coefficients averaged 93.7, 94.3 and 95.1%, respectively.

Nitrogen balance increased linearly (P<.01, table 6) with increased feeding level. There were no differences among treatments for net protein utilization or biological value. Thus, at higher feeding levels, more nitrogen was consumed and the nitrogen was utilized with similar efficiency, so an improvement in nitrogen balance resulted.

The DE of the diet (table 6) was not affected by the dietary feeding levels. The ME of the diet decreased slightly as level of feeding increased. However, the differences for ME of the diet were not significant. The results are in agreement with the observations of Jimenez (1972) and DeGoey and Ewan (1975) that level of feed intake did not affect DE or ME. ME as percentage of DE for the diet was not significantly affected by feeding level, but a slight decrease was observed at higher levels of feeding of the dried skimmed milk diet. ME averaged 94.5% of the DE for the diet. NE of the diet was not significantly affected by feeding level, and an average value of 2.34 kcal/g was observed.

The percentage of empty body dry matter increased linearly (P<.01), and the percentage of empty body water decreased linearly (P<.01) as level of feeding of dried skimmed milk diet increased (table 7). A quadratic response (P<.01) was observed for the percentage of empty body nitrogen. Pigs fed at 3% of body weight had the highest percentage body nitrogen, decreased at 4% of body weight and increased slightly at 5% of body weight. Percentages of ether extract and kilocalories of energy per gram increased linearly (P<.01) as feeding level increased. The percentage ether extract of the experimental pigs was less than that of the initial slaughter group,

Table 7. Experiment 7619. Effect of level of feeding a diet containing dried skimmed milk on body composition

Item	Units	Level of feeding[a] 3	4	5	IS[b]	SE[c]
			Body composition			
Dry matter[d]	%	24.8	27.0	27.3	27.5	.5
Water[d]	%	75.2	73.0	72.7	72.5	.5
Ash	%	3.1	3.3	2.9	3.4	.2
Nitrogen[e]	%	3.7	3.5	3.6	3.5	.03
Ether extract[d]	%	4.0	6.6	7.3	7.5	.6
Energy[d,f]	kcal/g	1.25	1.51	1.55	1.59	.05
			Composition of daily gain			
Nitrogen[d,g]	g	6.2	8.1	13.7	--	.5
Ether extract[d]	g	0.0	13.7	27.2	--	2.5
Energy[d]	kcal	136	338	568	--	23.4
Ash[d]	g	4.2	7.3	9.8	--	.4

[a]Basal diet fed at 3, 4 and 5% body weight. Feeding levels were adjusted weekly.

[b]Initial slaughter group.

[c]Standard error.

[d]Significant linear effect of level of feeding ($P<.01$).

[e]Significant quadratic effect for level of feeding ($P<.01$).

[f]Significant difference between initial and final composition ($P<.05$).

[g]Significant quadratic effect for level of feeding ($P<.05$).

but the difference was not significant. Carcass energy of the experimental group was significantly less ($P<.05$) than the initial slaughter group. The difference in energy composition between the experimental animals and the initial slaughter group was caused mainly by the difference in ether extract content of the groups. A similar result was reported by DeGoey and

Ewan (1975). There was no difference among treatments in percentage empty body ash.

Nitrogen, ether extract, ash and energy gained daily by pigs fed dried skimmed milk diet increased linearly ($P<.01$) as level of feeding increased (table 7). At higher levels of feeding, pigs consumed more feed and daily gain of nitrogen, ether extract, ash and energy increased.

The DE of dried skimmed milk (table 8) was not significantly affected by dietary feeding levels, although the DE increased slightly for pigs fed at 5% of body weight. An average DE value of 4.28 kcal/g dry matter was observed for dried skimmed milk in this study. The observed value compared favorably well with a value of 4.38/g dry matter reported by Morgan et al. (1975a) in experiments with older (45-70 kg) pigs. Values that have been reported in the literature for DE of dried skimmed milk averaged 4.16 kcal/g dry matter (Ewan, 1976). The observed DE:GE ratio (table 8) of 99.26% indicated that the energy of dried skimmed milk was well digested by young pigs. This is the highest DE:GE ratio observed in energy studies with young pigs at this University.

The ME of dried skimmed milk (table 8) was not significantly affected by the level of feeding the test diet, and an average value of 4.0 kcal/g dry matter was observed. Thorbek (1969) reported a ME value of 3.82 kcal/g dry matter, and Morgan et al. (1975a) observed the ME of dried skimmed milk to be 4.13 kcal/g dry matter. ME values of dried skimmed milk reported in literature ranged from 3.53 to 4.13 kcal/g dry matter (Ewan, 1976). The ME of dried skimmed milk in this trial fell within this range. In this trial, ME as a percentage of DE averaged 93.6% for dried skimmed milk (table 8). This value compared favorably well with a calculated value of 94.3%

Table 8. Experiment 7619. Energy availability and energy ratios of dried skimmed milk

Item	Unit	Level of feeding[a] 3 Mean	3 SE[b]	4 Mean	4 SE	5 Mean	5 SE	Pooled Mean	Pooled SE
				Air-dry basis					
DE	kcal/g	4.08	.014	4.09	.014	4.11	.014	4.09	.008
ME	kcal/g	3.84	.041	3.84	.041	3.81	.041	3.83	.024
NE	kcal/g	2.23	.170	2.28	.170	2.21	.170	2.24	.098
				Dry-matter basis[c]					
DE	kcal/g	4.27	.015	4.27	.015	4.29	.015	4.28	.008
ME	kcal/g	4.01	.043	4.01	.043	3.98	.043	4.00	.025
NE	kcal/g	2.32	.178	2.38	.178	2.31	.178	2.34	.102
				Energy ratios					
DE:GE	%	99.03	.35	99.17	.35	99.58	.35	99.26	.20
ME:DE	%	94.05	.91	93.93	.91	92.70	.91	93.56	.52
NE:ME	%	58.05	4.57	59.24	4.57	58.09	4.57	58.46	2.64
HI	%	41.95	4.57	40.76	4.57	41.91	4.57	41.54	2.64

[a]Basal diet fed at 3, 4 and 5% of body weight. Feeding levels were adjusted weekly.

[b]Standard error.

[c]Dried skimmed milk contained 4.301 kcal per gram dry matter and 95.74% dry matter.

obtained from the data of Morgan et al. (1975a). Young (1972) reported that ME:DE ratio for soybean meal averaged 92.5%, and Ewan (1976) observed that ME:DE ratio of soybean meal (50% crude protein) was 94.6%. The observed value of 93.6% for ME:DE of dried skimmed milk in this study differed from the findings of Diggs et al. (1965) that the ME:DE ratio of high protein feeds averaged 81.5%. The DE of dried skimmed milk was efficiently utilized by young pigs in this study.

No difference was observed between treatments for NE value of dried skimmed milk (table 8). The average NE value of dried skimmed milk was 2.34 kcal/g dry matter. NE values of protein feeds are very scarce in the literature, with the exception of studies reported from this University and hence comparison of NE values obtained in the present study with values of other investigators is difficult. However, the performances of pigs fed dried skimmed milk diets have been studied by several investigators.

Barber et al. (1965) reported improved efficiency of feed utilization and better performance of pigs fed liquid skimmed milk diet compared with pigs not receiving skimmed milk. Cooke and Chamberlain (1967) fed 16-90 kg pigs and reported increased proportions of muscle/fat in the carcass with increased level of milk in the diet. Chamberlain and Lucas (1968) in another experiment with pigs compared diet containing separated milk with an all meal-diet. They reported higher killing out percentages for pigs fed separated milk diet. Adam (1969), experimenting with pigs, reported improved digestibility of nitrogen and gross energy with increased level of skimmed milk in the diet. The percentage of lean to back fat thickness of pigs also improved with increased level of dietary skimmed milk. All these studies and the data obtained in our trial demonstrated the improved performance of pigs fed a diet containing dried skimmed milk and lend some support to the high NE value of dried skimmed milk observed in the present trial.

El-Kotoury et al. (1975), in experiments with chicks, reported calculated and determined values of 1.35 and 1.21 kcal/g dry matter, respectively, as the productive energy (NE) of dried skimmed milk. The productive energy was calculated using the equation derived by Fraps. The disparity between the value obtained with chicks and the NE value obtained in the present study with pigs could be because of species difference and differences in efficiency of energy utilization.

The NE:ME ratio (table 8) or efficiency of utilization of ME of dried skimmed milk for energy gain by young pigs was not significantly affected by feeding level. An average value of 58.5% was obtained for NE:ME ratio. Thus, HI of dried skimmed milk averaged 41.5%. This compared favorably well with a value of 44.9% as HI of soybean meal (Ewan, 1976).

Experiment 7711

Average daily gain of pigs fed the diet containing peanut meal increased linearly ($P<.01$), but feed conversion efficiency was not significantly affected as level of feeding increased (table 9). The apparent digestion coefficients (ADC) of dry matter, nitrogen and energy were not affected by feeding levels. Dry matter, nitrogen and energy ADC averaged 89.0, 90.4 and 89.9%, respectively.

Apparent nitrogen balance of pigs increased linearly ($P<.01$) as level of feeding the test diet increased (table 9). NPU and BV were not significantly affected by feeding levels. At higher levels of feeding, more feed was consumed, and more nitrogen was retained by pigs, but the efficiencies of nitrogen utilization in terms of NPU and BV were unaffected. The differences in nitrogen balance were because more nitrogen was consumed.

The DE and ME values of the diet (table 9) were not different among treatments, and average values of 4.06 and 3.86 kcal/g dry matter, respectively, were observed. ME as percentage of DE was not significantly different between treatments, and the DE of the diet was well utilized for ME.

Table 9. Experiment 7711. Effect of level of feeding a diet containing peanut meal on performance, digestion and metabolism[a]

Item	Units	Level of feeding[b] 3	4	5	SE[c]
			Pig performance		
Daily gain[d]	g	146	216	287	11
Feed:gain		1.44	1.39	1.35	.05
			Apparent digestion coefficient		
Dry matter	%	88.9	89.1	89.0	.4
Nitrogen	%	90.8	90.7	89.6	.6
Energy	%	90.2	89.9	89.7	.4
			Nitrogen metabolism		
Balance[d,e]	g	166	234	306	16
NPU[f]	%	53.9	52.6	53.4	2.6
BV[g]	%	59.4	58.0	59.6	2.9
			Energy metabolism		
DE	kcal/g	4.07	4.06	4.06	.02
ME	kcal/g	3.88	3.85	3.84	.01
ME	% DE	95.3	94.7	94.6	.2
NE	kcal/g	2.64	2.56	2.35	.06

[a]Averaged over the 28-day period.

[b]Basal diet fed at 3, 4 and 5% of body weight. Feeding levels were adjusted weekly.

[c]Standard error.

[d]Significant linear effect of level of feeding ($P<.01$).

[e]Nitrogen intake less fecal and urinary nitrogen for 28 days.

[f]Nitrogen balance as a percentage of nitrogen consumed.

[g]Nitrogen balance as a percentage of nitrogen consumed less fecal nitrogen.

The ME:DE ratio averaged 94.9% for the peanut meal diet. The NE of the diet containing peanut meal (table 9) was not significantly affected by level of feeding, although slight decreases were observed as feeding levels increased.

The percentages of empty body dry matter, water and nitrogen and kilocalories of energy per gram were not significantly affected by feeding levels (table 10). No difference was observed between the experimental group and the initial slaughter group for these body components. Empty body ash was significantly lower ($P<.01$), and ether extract significantly greater ($P<.05$) in the experimental group compared with the initial slaughter group. With increased weight gain by pigs in this experiment, the percentage composition of pigs that is ash rather than remaining constant decreased with compensatory gain in other body components such as ether extract. Kilocalories of energy per gram, which is influenced most by ether extract gain, was greater in the experimental group than the initial slaughter group, but the difference was not statistically significant. The daily gain of nitrogen, ether extract and energy increased linearly ($P<.01$) as level of feeding increased (table 10), but the gain in ash was not affected by feeding level.

The DE of peanut meal was not affected by dietary feeding level (table 11), but ME decreased linearly ($P<.05$) as level of feeding increased. DE and ME of peanut meal averaged 4.66 and 4.34 kcal/g dry matter, respectively. Morgan _et al_. (1975a) reported DE and ME values of 4.27 and 3.86 kcal/g dry matter, respectively, for peanut meal. Literature values of DE and ME values of peanut meal using swine averaged 3.49 and 3.19 kcal/g dry matter, respectively (Ewan, 1976). Lodhi _et al_. (1976) evaluated peanut

Table 10. Experiment 7711. Effect of level of feeding a diet containing peanut meal on body composition

Item	Unit	Level of feeding[a] 3	4	5	IS[b]	SE[c]
		Body composition				
Dry matter	%	24.5	26.1	26.7	25.0	.8
Water	%	75.5	73.9	73.3	75.0	.8
Ash[d]	%	3.1	2.7	2.5	3.6	.2
Nitrogen	%	2.5	2.5	2.4	2.5	.05
Ether extract[e,f]	%	6.3	7.9	9.3	5.4	.7
Energy	kcal/g	1.48	1.70	1.70	1.49	.09
		Composition of daily gain				
Nitrogen[g]	g	3.5	5.3	6.4	--	.4
Ether extract[g]	g	11.2	21.8	33.5	--	1.9
Energy[g]	kcal	218	400	513	--	32
Ash	g	3.8	3.8	4.9	--	.9

[a]Basal diet fed at 3, 4 and 5% of body weight. Feeding levels were adjusted weekly.

[b]Initial slaughter group.

[c]Standard error.

[d]Significant difference between initial and final composition ($P<.01$).

[e]Significant difference between initial and final composition ($P<.05$).

[f]Significant linear effect of level of feeding ($P<.05$).

[g]Significant linear effect of level of feeding ($P<.01$).

meal from different sources in experiments with chicks and observed ME values ranging from 2.0 to 3.05 kcal/g dry matter. However, Guirguis (1975) reported a value of 3.52 kcal/g dry matter as the ME of peanut meal fed to chicks.

Young <u>et al</u>. (1977), discussing the discrepancy in the range of values reported for DE of soybean meal, attributed the range in reported values to

Table 11. Experiment 7711. Energy availability and energy ratios of peanut meal

Item	Unit	Level of feeding[a] 3 Mean	SE[b]	4 Mean	SE	5 Mean	SE	Pooled Mean	SE
					Air-dry basis				
DE	kcal/g	4.51	.035	4.48	.035	4.46	.035	4.48	.020
ME[c]	kcal/g	4.24	.027	4.16	.027	4.14	.027	4.18	.016
NE	kcal/g	3.27	.198	3.11	.198	2.67	.198	3.02	.114
					Dry-matter basis[d]				
DE	kcal/g	4.68	.036	4.65	.036	4.64	.036	4.66	.021
ME[c]	kcal/g	4.40	.028	4.32	.028	4.30	.028	4.34	.017
NE	kcal/g	3.40	.206	3.23	.206	2.78	.206	3.14	.119
					Energy ratios				
DE:GE	%	93.09	.72	92.50	.72	92.22	.72	92.60	.42
ME:DE	%	93.99	.44	92.82	.44	92.66	.44	93.16	.26
NE:ME	%	70.68	4.81	68.25	4.81	57.99	4.81	65.64	2.78
HI	%	29.31	4.81	31.75	4.81	42.01	4.81	34.36	2.78

[a]Basal diet fed at 3, 4 and 5% of body weight. Feeding levels were adjusted weekly.

[b]Standard error.

[c]Significant linear effect of level of feeding ($P<.05$).

[d]Peanut meal contained 96.20% dry matter and 5.031 kcal per gram of dry matter.

differences in experimental technique between research groups. The difference in experimental technique could be responsible for some of the differences between our values and values obtained by other investigators.

The fiber content of peanut meal is another important factor that could account for differences in DE and ME values reported by different investigators. Comparing the DE values of soybean meals with the acid detergent fiber contents of soybean meals, Young *et al.* (1977) observed that soybean meals with higher acid detergent fiber had lower energy values.

Another possible explanation for the differences between average values reported by other investigators and the values obtained in this study might be because of the age of the pigs. Saben et al. (1971a), investigating DE and ME values of soybean meals in experiments with pigs of different age groups, observed that DE, ME and ME_n decreased as weight of the pigs increased.

Also, the peanut meal used in this study was mechanically extracted, and as Lodhi et al. (1976) observed, ME content of peanut cake derived from single-phase extraction was higher than that of four phase extraction. Hill and Renner (1960) reported low ME and poor digestibility of protein feedstuffs due to overheating. The processing method of peanut meals could also contribute to differences in reported DE and ME values.

Thus, differences in experimental techniques, the acid detergent fiber content of the peanut meal, the age of the pigs and the method of processing peanut meal all could have resulted in the higher DE and ME values obtained in the present study.

The NE of peanut meal (table 11) was not affected by dietary feeding levels, and an average value of 3.14 kcal/g dry matter was observed in this study. This compared favorably with a value of 3.24 kcal/g digestible organic matter reported by Nehring and Haenlein (1973) as the net energy fat (NEF) for peanut oil meal in experiments with pigs. The NE of peanut meal was greater than the NE of dried skimmed milk or meat and bone meal determined in these studies or of soybean meal reported by Ewan (1976). Peanut meal contained 6.12% ether extract (Appendix B), which was far greater than the ether extract content of dried skimmed milk or soybean meal. Because ether extract has a higher energy value and is utilized efficiently, the NE of peanut meal was greater than the NE of dried skimmed milk or soybean meal.

The energy digestibility (DE:GE, table 11) of peanut meal was 92.6%. ME:DE ratio averaged 93.2%, and NE was 65.6% of ME. The efficiencies of utilization of GE, DE and ME were not affected by dietary feeding levels. HI associated with the utilization of ME for NE gain was 34.4%. This represents the proportion of energy lost as heat in the utilization of ME of peanut meal for gain by young swine. This HI value is the smallest value of the three protein feeds investigated in the present study and is smaller than the value of 44.9% for soybean meal (Ewan, 1976). The value of 34.4% for HI of peanut meal compared favorably with the observed value of 30% as the HI associated with growth (Baldwin, 1968).

GENERAL DISCUSSION

Some of the methods that have been used by different investigators to evaluate the energy values of high protein feeds are questionable in terms of formulation of diets. Young et al. (1977) cited differences in experimental techniques as one of the factors responsible for the disparity in energy values that have been reported in the literature.

One major point to be considered in energy evaluation of protein sources is the need to limit dietary protein level to that which meets the animals requirements for the essential amino acids. Diggs et al. (1965) and Saben et al. (1971a, b) evaluated energy values of protein sources for swine. The high protein ingredients evaluated in these studies were added to basal diets containing about 39% protein and resulted in very high protein test diets. Energy values obtained for feedstuffs using such an approach are low, and as May and Bell (1971) observed, one major problem is the testing of high protein feedstuffs at dietary levels far in excess of the normal level of use.

Level of protein has profound effect upon the utilization of DE and the ME:DE ratios. Lower values were observed for ME of high protein feeds when the level of the ingredient in the diet was high in the ration or when the protein level of the basal ration was high (May and Bell, 1971). If high dietary protein levels are fed, excess amino acids are catabolized with the resultant inefficient utilization of dietary energy. Morgan et al. (1975a) have reported that the decrease in ME:DE ratio of diets with increasing protein content of the diet reflected increased catabolic processes and greater excretion of urinary nitrogen. The approach using high dietary protein levels for evaluating protein feeds may be suitable for obtaining energy values on complete degradation of the amino acids but is not adequate for evaluating energy utilized for growth.

Some investigators (Hill and Renner, 1960; Saben et al., 1971b; Guirguis, 1975, 1976; Lodhi et al., 1976) have fed diets in which the protein source being evaluated was combined with several other protein sources in the basal diet. Associative effects on energy utilization were assumed to be negligible. These investigators should have formulated their diets using the protein sources of interest as the main protein contributor and balanced the diets using synthetic amino acid mixtures. It is felt that until there is conclusive evidence that there are no associative effects at all levels of energy utilization, such an approach has faults.

The approach used in our study was to formulate the basal diets with the protein source of interest as the main protein source, and the energy furnished by corn, protein source, soybean oil and vitamin-additive premix. The protein level of the diets was about 28% on as fed basis. Attempt was made to limit the protein content of the diet such that excess amino acids are not catabolized, resulting in inefficient utilization of energy gain by pigs. In evaluating protein rich feedstuffs, Morgan et al. (1975a) formulated a basal diet that consisted of barley and mineral and vitamin supplements. The final diets contained 20 to 26% crude protein on dry matter basis. Most of the energy values reported in the present studies compare favorably with values obtained by Morgan et al. (1975a).

The basal diets in our experiments were fed at 3, 4 or 5% of body weight. DeGoey and Ewan (1975) reported that the level of feeding the basal diet had no significant effect on energy values of diets and of test feeds. Except for NE value of meat and bone meal, level of feeding had no significant effect on energy values of protein sources or diets in the present studies.

However, data from the present studies indicated that meat and bone meal is of low biological value. At a level of about 43% in the diet of young pigs, amino acid and mineral imbalances probably adversely affected energy utilization for gain. The performance data (table 3) supported this. Perhaps, better responses will be obtained if the basal diet contained about 20 to 30% meat and bone meal. The diet should be balanced for the essential amino acids and fed to pigs at 3, 4 or 5% of body weight.

SUMMARY

Three randomized block experiments were conducted to evaluate the utilization of energy from three protein sources by young swine. Each experiment was a metabolism study with total collection of urine and feces for 28 days. Energy gain was determined by the comparative slaughter technique by measuring the difference in energy content of an initial slaughter group and the experimental groups. Corn-protein source diet was fed at 3, 4 or 5% of body weight daily to swine of average initial age of 24 days and average initial body weight of 5.3 kg.

Average daily gain (ADG) and feed:gain (F:G) ratio of pigs fed a diet containing 43% meat and bone meal were not significantly affected by level of feeding. Apparent digestibility coefficients of dry matter, nitrogen and energy averaged 73.3, 81.5 and 80.4%, respectively, and were not significantly different between treatments. Meat and bone meal diet was poorly utilized by baby pigs, and performance of pigs was poor. The poor performance of pigs fed meat and bone meal diet and the poor utilization of metabolizable energy of meat and bone meal for energy gain may be because of amino acid and mineral imbalances. The efficiency of utilization of ME (NE:ME) and the net energy value of meat and bone meal decreased as feeding level increased. The energy values of meat and bone meal in kilocalories per gram of dry matter were: gross energy (GE), 4.23; digestible energy (DE), 3.09; metabolizable energy (ME), 2.88; and net energy (NE), .86.

As the level of feeding increased, average daily gain of pigs fed a diet containing dried skimmed milk as a protein source increased linearly ($P<.01$), but F:G ratio was not significantly affected. Energy values of

dried skimmed milk were not significantly affected as level of feeding increased and were in kilocalories per gram of dry matter: GE, 4.30; DE, 4.28; ME, 4.00; and NE, 2.34.

For young pigs fed peanut meal diet, ADG increased linearly ($P<.01$), but F:G ratio was not affected as level of feeding increased. Level of feeding had no significant effect on the apparent digestibility coefficients for dry matter, nitrogen or energy. Energy values of peanut meal were not affected by level of feeding and were in kilocalories per gram dry matter: GE, 5.03; DE, 4.66; ME, 4.34 and NE, 3.14.

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APPENDIX A.

CALCULATIONS OF ENERGY VALUES

Feed Consumed

Grams of ingredient consumed was obtained by multiplying the grams of feed consumed by the percentage of the diet that was ingredient, e.g., 5986.6 g x .6989 = 4184 g. The total grams of feed consumed minus the grams of ingredient gave the quantity contributed by other dietary components, e.g., 5986.6 - 4184 = 1802.6.

Gross Energy

GE of ingredients and the diet were determined by bomb calorimeter. GE per gram of other dietary components times grams of feed consumed gave the GE attributable to other dietary components (5986.6 x 1.326 = 7938.23 kcal). GE per gram of ingredient multiplied by the amount of ingredient consumed gave the GE that was contributed by the ingredient (4184 x 4.124 = 17254.82 kcal).

Digestible Energy

The grams of feed consumed multiplied by DE per gram of other dietary components gave DE for other dietary components (5986.6 x 1.137 = 6806.76 kcal). The fecal energy (FE) was partitioned between the test feed ingredient and other dietary components. FE attributable to other dietary components was obtained by deducting DE of other dietary components from GE of other dietary components (7938.23 - 6806.76 = 1131.47 kcal). The total FE, obtained by multiplying GE/g dry feces by grams of dry feces, minus FE attributed to other dietary components gave the FE for the test ingredient (1566 - 1131.47 = 434.53 kcal).

GE of the test feed ingredient minus FE attributed to the test ingredient gave the DE of the test ingredient (17254.82 - 434.53 = 16820.29 kcal). The DE of the test ingredient divided by grams of ingredient consumed gave the DE/g of ingredient (16820.29 ÷ 4184 = 4.02 kcal/g).

Metabolizable Energy

Total grams of feed consumed multiplied by ME per gram of other dietary components gave the ME of other components (5986.6 x 1.098 = 6573.29 kcal). The urinary energy was partitioned thus:

> DE of other dietary components minus ME of the components gave the urinary energy attributed to the other dietary components (6806.76 - 6573.29 = 233.47 kcal). The total urinary energy minus urinary energy of other dietary components gave the urinary energy attributed to the test ingredient (1331 - 233.47 = 1097.53 kcal).

The DE of ingredient minus urinary energy of ingredient gave the ME for the ingredient (16820.29 - 1097.53 = 15722.76 kcal). ME per gram of ingredient was calculated by taking ME of ingredient and dividing by grams of ingredient consumed (15722.76 ÷ 4184 = 3.758 kcal/g).

In the present study with high protein feeds, ME was not corrected to nitrogen equilibrium because correction of ME to zero nitrogen retention will be unrealistic, since young swine are expected to grow and deposit nitrogen in the growth process.

Net Energy

In this and other studies that have been reported from this University, NEm has been estimated from energy gain, EG (Ewan, 1976).

Previous trials (Jimenez, 1972; DeGoey and Ewan, 1975; Ewan, 1976) have shown that EG is highly correlated with ME intake. From summary of data collected in trials (Jimenez, 1972; DeGoey, 1973; Phillips, 1974; Pals and Ewan, 1976; Robles, 1976) feeding basal diets of the same composition, the relationship is given by this equation:

$$y = .61x - 71.017$$

where Y = EG and x = ME intake, in kilocalories per day per $W^{.75}$. The extrapolation of the regression of EG to zero ME intake gave the estimate of ME required for maintenance (NEm, Figure 2) because HI is zero at zero ME intake. The linear relationship between EG and energy intake showed that energy was utilized by young pigs as efficiently for production (gain) as for maintenance. The NE for maintenance (NEm) was calculated as follows:

$$\text{NEm} = 71.017 \text{ kcal}/W^{.75}/\text{day} \times W^{.75} \times \text{days on experiment.}$$
$$\text{NEm} = 71.017 \times 5.261 \times 28 = 10461.37 \text{ kcal}$$

NE per gram of feed was calculated as follows:

$$\text{NE/g of feed} = \frac{\text{NEm} + \text{EG}}{\text{Gram of feed consumed}}$$

$$\text{NE/g of feed} = \frac{10461.37 + 6718.06}{5986.6} = \frac{17179.43}{5986.6} = 2.87 \text{ kcal/g}$$

NE per gram of ingredient was calculated as follows:

$$\frac{\text{NEm} + \text{EG} - (\text{NE/g of other dietary components} \times \text{g of feed consumed})}{\text{g of ingredient consumed}}$$

$$\text{NE/g of ingredient} = \frac{17179.43 - (.771 \times 5986.6)}{4184} = 3.003 \text{ kcal/g}$$

APPENDIX B.

CHEMICAL ANALYSIS OF DIETS AND PROTEIN SOURCES

Table B1. Calculated analysis of basal diets

Item	Experiment 7610	Experiment 7619	Experiment 7711	Requirement
Calcium, %	4.99	.89	.74	.8
Phosphorus, %	2.62	.79	.85	.6
Magnesium, mg	5703	1226	2336	400
Zinc, mg	105	125	107	100
Cu, mg	7.9	14.4	7.27	6
Vitamin A, IU	5530	3738	4986	2200
Vitamin D, IU	244	523	244	220
Vitamin E, IU	71	71	69	11
Vitamin K, mcg	652	625	644	10
Riboflavin, mg	6.25	17.6	6.8	3
Niacin, mg	59.3	40.5	118	22
Choline, mg	1350	1354	1249	1100
Pantothenic Acid, mg	16	36.9	37	13
Arginine, %	1.78	.93	2.95	.28
Isoleucine, %	.97	1.73	1.13	.69
Leucine, %	1.86	2.56	2.16	.83
Valine, %	1.23	1.64	1.32	.69
Lysine, %	1.77	2.08	.97	.96
Phenylalanine, %	3.36	1.17	1.46	.68
Threonine, %	.97	1.07	.86	.62
Tryptophan, %	.17	.32	.27	.18
Methionine, %	.81	1.14	.8	.51
Cystine, %	.31	.34	.04	.28

Table B2. Analytical results of diets and protein sources

Item	Units	Experiment 7610		Experiment 7619		Experiment 7711	
		Basal diet	Meat and bone diet	Basal diet	Dry skimmed milk	Basal diet	Peanut meal
Dry matter	%	93.14	92.08	94.29	95.74	92.13	96.20
				Dry matter basis			
Ash	%	14.35	30.55	6.98	8.60	5.53	4.46
Crude fiber	%	2.64	1.93	.70	.10	3.22	4.15
Ether extract	%	10.23	10.46	4.08	.11	7.95	6.12
NFE	%	42.48	-.77	57.89	50.55	47.66	26.85
Protein	%	30.31	57.61	30.18	38.32	35.64	58.42
Nitrogen	%	4.85	9.22	4.83	6.13	5.70	9.35
Organic matter	%	85.66	69.45	93.02	91.40	94.47	95.54
Cell counts	%	77.26	65.15	95.72	99.99	82.22	85.79
Cell walls (NDF)	%	22.74	34.85	4.29	.01	17.78	14.21
Cellulose	%	2.66	1.75	.55	.00	3.23	4.47
ADF	%	3.78	4.10	.79	.00	4.73	6.08
Lignin	%	1.24	1.81	.28	.00	1.49	1.11
Hemicellulose	%	18.96	30.75	3.50	.01	13.08	8.13
Silica	%	.00	.59	.00	.00	--	--
Gross energy	kcal/g	4.52	4.23	4.52	4.31	4.88	5.03