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FATS AND PROTEINS RESEARCH FOUNDATION, INC.

DR. GARY G. PEARL D.V.M.
Director Technical Services

16551 Old Colonial Road
Bloomington, Illinois 61704
Telephone: 309-829-7744 FAX: 309-829-5147
<www.fprf.org>

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Metabolizable Energy Value of Meat and Bone Meal

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Objectives:

1) To determine the digestible and metabolizable energy values of a variety of samples of meat and bone meal for pigs.

2) Assess the variation in digestible and metabolizable energy content of meat and bone meal and develop robust regression equations that relate the variation to chemical composition.

Summary of Project Results

We received twelve 150-lb samples of Meat and Bone Meals, and conducted analyses of these samples for gross energy (GE), dry matter (DM), crude protein (CP, N x 6.25), crude fat, calcium (Ca), and phosphorus (P). The P contents of all the 12 samples vary from 2 to 6%, Ca from 5 to 14% and crude protein vary from 46 to 61%. The percent ash and crude fat for the 12 samples vary from 19 to 35% and 8 to 15%, respectively. The metabolizable energy (ME) and nitrogen-corrected metabolizable $\mathrm{ME_n}$ of the 12 MBM samples ranged between 1,569 and 3,308 and 1,474 and 3,361 kcal / kg dry matter.

ABSTRACT: Metabolizable energy (ME) and nitrogen-corrected ME ($\mathrm{ME_n}$) values of 12 samples of meat and bone meal (MBM) were determined using 288 barrows with an average weight of 35 kg. For each of 12 MBM samples, diets were formulated by substituting 0, 5, or 10 % MBM in a basal 170 g CP/kg corn-soybean meal diet; corn and soybean meal were adjusted at the same ratio to account for the substitution. Each diet was fed to 8 barrows in individual metabolism crates in metabolism studies that employed a 5-d acclimation followed by a 5-d period of total but separate collection of feces and urine. The gross energy (GE), CP, crude fat (CF), ash, Ca, and P contents of the MBM samples, on per kg dry matter basis, ranged from 3,493 to 4,732 kcal, 496.7 to 619.1 g, 91.1 to 151.2 g, 200.3 to 381.9 g, 54.3 to 145.8 g, 25.6 to 61.7 g, respectively. For each of the 12 MBM samples, MBM intake and MBM contribution to ME and ME_n increased linearly ($P < 0.05$) with increasing level of MBM in the diets. The ME and ME_n content of each of the MBM sample was calculated from the slope of the regression of MBM contribution (in kcal) to ME and ME_n intake, respectively, against amount (in kg) of MBM intake. The ME of the 12 MBM samples ranged from 1,569 to 3,308 kcal/kg DM; corresponding figures for ME_n were 1,474 to 3,361 kcal/kg DM. The variation in ME was described by the regression equation ME = 6,982 + 0.283 GE (kcal/kg) – 6.26 CP (g/kg) – 3.75 CF (g/kg) + 129.47 P (g/kg) – 54.91 Ca (g/kg) – 6.57 Ash (g/kg) with R^2 of 0.612 and SD of 376. Corresponding equation for ME_n= 3,937 + 1.089 GE (kcal/kg) – 8.74 CP (g/kg) + 3.58 CF (g/kg) + 60.89 P (g/kg) – 15.92 Ca (g/kg) – 9.57 Ash (g/kg) with R^2 of 0.811 and SD of 314. Simpler regression equations describing variation in ME or ME_n were 9,254 – 7.41 CP (g/kg) – 9.41 Ash (g/kg) with R^2 of 0.504 and SD of 278 or 12,504 – 10.71 CP (g/kg) – 13.44 Ash (g/kg) with R^2 of 0.723 and SD of 249. Pearson's correlation analysis revealed that the variations in ME or ME_n of the MBM samples were not related to any of the major chemical components. The results reveal that variation in each of the chemical components of MBM alone is not the sole determinant of ME or ME_n content of MBM but that the interactions among these components influence energy utilization in MBM for pigs.

Key Words: Meat and bone meal, Metabolizable energy, Pig, Regression, Slope

Introduction

Meat and bone meal (MBM) is rendered animal offal, including restaurant grease, plate waste, trimmings and bones, viscera, and undigested feed, blood, heads, hooves, hides, and dead livestock, that are considered unfit for human consumption (Shirley and Parsons, 2001). The rendering of wide variety raw materials can result in differences in nutrient and energy content of MBM. The nutritional significance of MBM nutrient and energy content necessitates information on utilization of these ingredient components by the animal. Utilization of nutrients and energy contained in meat and bone meal rely on changes in amounts between that offered in feed and output in feces plus urine. With utilization information in hand, decisions can be made about the most cost-effective use of MBM in diet formulation.

Using 14 samples of MBM from rendering plants in Australia, Batterham et al. (1980) reported DE values between 2,393 and 3,585 kcal/kg DM in growing pigs. However, the ME content of the MBM was not determined in the study reported by Batterham et al. (1980). In another study, Shi and Noblet (1993) reported ME of 2,175 and 3,011 kcal/kg DM for growing pigs and sows, respectively for one sample of MBM from rendering plants in France. These two studies (Batterham et al., 1980 and Shi and Noblet, 1993) are the only reports found in the literature that specifically determined the energy values of MBM for pigs. The importance of accurate and reliable ME values for MBM becomes evident when one considers the fact that energy is the most expensive component of swine diet. The objective of this study was to determine the ME and ME_n in 12 samples of MBM for pigs, and to develop regression equations that describe the variation in ME or ME_n of MBM in relation to chemical composition.

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Correspondence: O. Adeola, Email: ladeola@purdue.edu

Materials and Methods

Meat and bone meal samples

Twenty-four samples of MBM were selected from different regions of the United States and analyzed for proximate composition. Twelve of the samples were selected intentionally to provide a wide range of chemical composition and used in these experiments to determine the ME and ME_n for pigs. Sample 1was derived from all beef packer slaughter material processed via a Dupps Continuous Cooker at 129 to 135°C. Sample 2 was derived from a high percentage of beef packer slaughter material with small component of extra offal and swine raw material and processed via a Dupps Continuous Cooker as described for Sample 1. Sample 3 was derived from 30% bovine whole carcasses and 65% swine whole carcasses with small component of meat processing trimmings of multiple species and processed as described for Sample 1. Sample 4 was derived primarily from whole cattle carcasses with small amounts of mixed species processing trim and beef packer slaughter material. Sample 5 was composed of mixed species raw material derived from processing trim and bone and processed as described for Sample 1. Sample 6 was composed of mixed species raw material derived from pork slaughter, beef packer slaughter and beef processing trim and bone of approximately 70% beef and 30% pork plus small quantity of poultry processing and whole bird carcasses and processed as described for Sample 1. Sample 7 was derived from all slaughter and processing material with no whole carcasses included, mixed raw material of both beef and pork slaughter and processing with near equal quantities from both species and processed as described for Sample 1. Sample 8 was packer-derived material from exclusive swine slaughter and processed as described for Sample 1. Sample 9 was derived from 80% beef slaughter and processing, 10% whole beef and swine carcasses of near equal weight proportions, small amount of poultry heads, necks and discards and and processed as described for Sample 1. Sample 10 was derived from raw material composed of 60% beef packer material, 25% poultry backs and necks and 15% grocery store trimmings, outdated muscle meats and processed meats; and processed as described for Sample 1. Sample 11 was derived from beef and pork slaughter material of approximately equal proportions with up to 10% turkey slaughter and processing tissue comprising a higher bone content. There is no whole carcass material from either beef or swine and processed via a Dupps Continuous Cooker at 132° to 138°C. Sample 12 was derived from nearly exclusive all pork from packer processing sows for sausage and processed as described for Sample 1.

Diet formulation

Given that ME values are extremely difficult to determine directly using MBM as the sole source of dietary energy, each of the 12 MBM samples were used in diets formulated with 0, 5, or 10% MBM substitution of corn and soybean meal (SBM) in a basal 170 g CP/ kg corn-SBM diet. Corn and SBM were adjusted to constant ratio (1.8:5.5 for the 5% MBM diet and 3.6:11 for the 10% MBM diet) in the substitutions. Because all the energy in the basal diet is derived from corn and SBM, this constant ratio is key for algebraic equations (described below) used in the indirect method of ME determination to derive contribution of MBM to energy intake. To minimize the negative impact of N utilization of energy, the three diets for each MBM sample were formulated to have comparable CP content (Table 1). The same batch of corn and SBM were used for formulating all diets, the only source of variation was the 12 samples of MBM.

Pig metabolizable energy assay

The Purdue Animal Care and Use Committee approved all animal care procedures. Two hundred and eighty eight Yorkshire-Landrace barrows, with an average weight of 35 kg, were used in this study. The basal diet was corn-SBM based diet with 0 % MBM (Diet 1; Table 1). For each MBM sample, each of the 3 diets containing 0, 5, or 10% MBM (Diets 1, 2, or 3; Table 1) was fed to 8 barrows in a metabolism assay that employed a 5-d adjustment followed by a 5-d period of total but separate collection of feces and urine. Pigs were housed in stainless-steel metabolism crates that allowed separate collection of feces and urine using protocols described by Adeola and Bajjalieh, (1997). The 5-d adjustment period allowed the barrows to adjust to their new environment and attain an intake of approximately 5 % of their body weight at the beginning of the collection. They were fed equal amounts of diets twice daily (0700 and 1700). This amount was adjusted accordingly until each pig was able to consume all the feed given to it. On the morning of d 6, fecal trays and urine collection vessels containing 10 % formalin were placed under the metabolism crates to initiate collection of urine for 5 d. To be sure of when to begin fecal collection, 2 g of ferric oxide was fed in 100 g of assigned diet at the time of placement of the sample collection trays and screens. Feeding of the remaining portion of morning feed was after the ingestion of the 100 g of assigned diet and marker. The appearance of the marker in the feces signaled the beginning of fecal collection. On the morning of d 11, urine collection was terminated and 2 g of ferric oxide was again fed in 100 g of assigned diet. The appearance of the second marker in the feces signaled the termination of fecal collection. As it was on d 6, the feeding of the remaining feed was after ingestion of the 100 g of assigned diet plus 2 g of ferric oxide. Upon the appearance of the marker in the feces, fecal collection was terminated. Feces were collected once daily weighed and stored at -4°C. Urine was collected at the time of feces collection, measured in a graduated cylinder and a 35 % aliquot of urine was collected and frozen.

Chemical analysis

All MBM samples were analyzed for dry matter, GE, CP (N*6.25), CF, ash, Ca, P, and amino acids. Dry matter content was determined by drying the samples at 100°C for 24 h. Amino acids were determined by HPLC [AOAC 982.30 E (a, b, c), 2000]. Calcium and P were determined by inductively coupled plasma atomic emission spectroscopy (AOAC 990.08, 2000) and fat (AOAC 934.01, 2000). Nitrogen content of MBM was determined by the combustion method (Model FP2000, LECO Corp., St. Joseph, MI). Duplicate proximate analyses were performed on all the MBM samples at the University of Missouri Experiment Station Chemical Laboratory. The GE content of each MBM sample was determined by adiabatic bomb calorimetry (Model 1261, Parr Instrument Co., Moline, IL). The ash content was determined by drying the sample overnight at 100°C followed by ashing in a muffle furnace for 18 h at 600°C.

The frozen feces were thawed (the entire collection for each pig was pooled), placed in aluminum pan, weighed and dried at 55°C. The feces were then ground through a 0.5-mm screen to facilitate analysis. The urine collected was thawed, thoroughly mixed, and filtered through a glass wool. Known volumes (between 300 and 800 mL depending on the total volume produced) of duplicate urine samples were measured into aluminum pans and weighed. Urine was dried at 55°C, weighed and stored in Whirl-Pak bags at -18°C. The dried urine samples were then analyzed for GE and N. Duplicate analyses were performed on all the diets, feces, orts and urine samples. Dry matter content was determined by drying the samples at 100°C for 24 h. Nitrogen contents of the diets, feces, orts and urine samples were determined by the combustion method (AOAC 990.03, 2000) using a Leco model FP-2000 N analyzer (Leco Corp., St. Joseph, MI) using EDTA as a standard. Gross energy contents were determined by adiabatic bomb calorimetry model 1261 (Parr Instrument Co., Moline, IL) using benzoic acid as a standard.

Calculations

The ME content of the diet was calculated as the difference between energy in the diet intake and the sum of energy in the orts, feces, and urine. Metabolizable energy in Diet 1 (the basal diet, ME1) was contributed by 0.715 corn (C) and 0.235 soybean meal (SBM). Thus:

$$ME1 = 0.715\ C + 0.235\ SBM \qquad [\text{Eqn. 1}]$$

Metabolizable energy in Diet 2 (the diet containing 5 % MBM, ME2) was contributed by 0.733 C, 0.180 SBM and 0.05 MBM. Thus:

$$ME2 = 0.733\ C + 0.180\ SBM + 0.05\ MBM \qquad [\text{Eqn. 2}]$$

Metabolizable energy in Diet 3 (the diet containing 10 % MBM, ME3) was contributed by 0.750 C, 0.125 SBM, and 0.10 MBM. Thus:

$$\text{ME3} = 0.750\ \text{C} + 0.125\ \text{SBM} + 0.1\ \text{MBM} \qquad \text{[Eqn. 3]}$$

Using the ME contents of C and SBM at 3,420 and 3,385 kcal/kg (NRC, 1998), respectively and substituting and rearranging the equations above give:

$\text{ME} = (\text{ME2} - 0.96154\ \text{ME1}) / 0.05$; for contribution (kcal/kg) of MBM to ME of Diet 2 [Eqn. 4]

$\text{ME} = (\text{ME3} - 0.92203\ \text{ME1}) / 0.1$; for contribution (kcal/kg) of MBM to ME of Diet 3 [Eqn. 5]

The products of Eqn. 4 or 5 and the amounts (in kg) of MBM intake of pigs fed Diet 2 or 3, respectively, represent MBM contributions to ME intake (kcal) in pigs fed those respective diets (Diet 2 or 3). As indicated in the diet formulation section above, substitution of the constant ratio of corn and SBM with MBM formed the basis for equations 1 to 5. The ME corrected for retained nitrogen (ME_n) was calculated using a caloric value of 7.45 kcal/g of nitrogen (Harris et al., 1972).

Statistical analysis

The data for each MBM sample was analyzed as a randomized complete block design of 3 diets in 8 blocks, using the General Linear Models of SAS® (SAS Inst., Inc., Cary, NC). Orthogonal polynomial contrasts (linear and quadratic) were used to compare the treatment means. Meat and bone meal contribution to ME or ME_n intake in kilocalories was regressed against kilograms of MBM intake for each pig on each MBM sample using the PROC GLM of SAS® with block as a source of variation and solutions option. The slope of the regression gave the ME or ME_n content of the MBM sample. Pearson's correlations were generated using PROC CORR of SAS®, and multiple linear regression (PROC STEPWISE) analyses were carried out by regressing the ME or ME_n of MBM on the analyzed chemical constituents of the MBM samples.

Results

The chemical compositions of the twelve MBM samples are shown in Table 2. Crude protein and crude fat contents were between 496.7 and 619.1 and between 91.1 and 151.2 g/kg, respectively. Calcium and P concentrations of the MBM samples ranged between 54.3 and 145.8 and 25.6 and 61.7 g/kg, respectively. Meat and bone meal ash concentrations ranged from 200.3 to 381.9 g/kg; GE contents were between 3,493 and 4,732 kcal/kg (Table 2). The amino acid composition of the 12 samples of MBM, presented in Table 3, show a range, in percent, of 0.32 to 0.47 for tryptophan, 0.27 to 0.86 for cysteine, 0.50 to 0.84 for methionine, 1.37 to 2.18 for threonine, and 2.31 to 3.29 for lysine. These analyses results presented in Tables 2 and 3 revealed that MBM samples 6 and 11 were high in CP and amino acids but those of MBM samples 1 and 2 were relatively low. There was an increase in GE and fat contents of diets with increase in MBM substitution (data not shown). Similarly, the ME and ME_n values of diets increased as MBM substitution increased from 0 to 10% except for MBM sample number 2, where there was a decrease (data not shown).

Meat and bone meal intake of pigs over the 5-d collection period increased linearly ($P < 0.05$) with increase in MBM inclusion in the diet for the 12 MBM samples (Table 4). Quadratic response ($P < 0.05$), as well as linear response, in MBM intake were observed for MBM sample number 6. The contribution of MBM to ME and ME_n intakes in pigs that received diets with MBM added at 0, 5 , or 10% are presented in Tables 5 and 6, respectively. The inclusion of 12 MBM samples resulted in linear increases ($P < 0.05$) in contribution of MBM to ME or ME_n intake. Quadratic responses ($P < 0.05$), as well as linear responses, in MBM contribution to ME or ME_n intake were observed for MBM sample numbers 1, 6, and 9. The slopes of the regression of MBM contribution to ME or ME_n intake in kilocalories on kilograms of MBM intake for each MBM sample, which produce the ME or ME_n for each MBM sample are presented in Table 7. Metabolizable energy values ranged from 1,569 to 3,308 kcal/kg DM; ME_n values were between 1,474 and 3,361 kcal /kg DM.

A perusal of the ME values of the 12 MBM samples relative to their chemical components revealed a curiously high ME for MBM sample number 1 and an atypically low ME for MBM sample number 2. Deletion of MBM samples 1 and 2 from the correlation and multiple linear regression analyses resulted in approximately 80 % reduction in variation and approximately 40% improvement in coefficient of determination. Pearson's correlation coefficients and multiple regression equations presented in Tables 8 and 9, respectively were therefore generated from MBM sample numbers 3 to 12. Correlation coefficients relating ME or ME_n to GE, CP, CF, P, Ca, and ash contents all had $P > 0.1$ (Table 8). Majority of the variation in the GE was negatively related to P, Ca, or ash contents of the MBM ($P < 0.001$). There were tendencies for negative correlations between CP and P or ash contents ($P < 0.1$).

Very weak predictive relationships were observed between ME or ME_n and any one of the individual chemical components as shown by the low R^2, which were in the range of 0.032 to 0.470 (Table 9). As expected, the greatest variation in ME was accounted for by using a combination of CP, CF, P, Ca, and ash contents of MBM and was described by the regression equation ME = 6,982 + 0.283 GE (kcal/kg) – 6.26 CP (g/kg) – 3.75 CF (g/kg) + 129.47 P (g/kg) – 54.91 Ca (g/kg) – 6.57 Ash (g/kg) with R^2 of 0.612 and SD of 376 (ME equation 7, Table 9). Corresponding equation for ME_n = 3,937 + 1.089 GE (kcal/kg) – 8.74 CP (g/kg) + 3.58 CF (g/kg) + 60.89 P (g/kg) – 15.92 Ca (g/kg) – 9.57 Ash (g/kg) with R^2 of 0.811 and SD of 314 (ME_n equation 7, Table 9). Simpler regression equations describing variation in ME or ME_n were 9,254 – 7.41 CP (g/kg) – 9.41 Ash (g/kg) with R^2 of 0.504 and SD of 278 (ME equation 13, Table 9) or 12,504 – 10.71 CP (g/kg) – 13.44 Ash (g/kg) with R^2 of 0.723 and SD of 249 (ME_n equation 13, Table 9). In general, fifty-two and seventy percent of the variation in the respective ME and ME_n of MBM samples could be explained by the variability in CP, CF and ash contents.

Discussion

One of the objectives of this study was to determine the ME and ME_n of MBM for pigs. Another goal was to develop regression equations that describe the variation in ME or ME_n of MBM in relation to chemical composition. Because feed accounts for more than sixty percent of the cost of producing market pigs and energy is the most expensive component of the diet, accurate information on the energy value of MBM is imperative for its cost-effective use in diet formulation, predictable growth performance of pigs fed such diets and reduced impact of pork production on the environment. Selection of the MBM samples used in the study was guided by a desire to increase the likelihood of observing a large amount of variability in ME contents. This was important in order to relate the variability in ME to variation in chemical components. In this respect, the range in ME or ME_n was between 1,569 and 3,308 kcal/kg DM or 1,474 and 3,361 kcal/kg DM, respectively.

The chemical composition of the MBM samples used in this study are similar to those reported by Young et al. (1977), Batterham et al. (1980), and Sibbald, et al. (1980). Furthermore, Shi and Noblet (1993), Wang and Parsons (1998) and Ravindran et al. (2002) also reported chemical composition of the MBM that are similar to those used in the current studies. However, Sartorelli et al. (2003) reported relatively lower values for CP and GE but relatively higher values for percent ash, P and Ca than the MBM used in the current studies. The MBM samples used in the study conducted by Sartorelli et al. (2003) had a relatively lower Ca:P ratio (ratio ranged from 1.59 to 2.13) which is lower than the ratio found in the MBM used in this study (Ca:P ratio from 2.12 to 2.42). Going by the definition of MBM as given by Scott and Dean (1991) four of the MBM samples in this study (samples number 3, 4, 6, and 11) with P content lower than 4 % may not fall into the definition of MBM. Unlike in the study carried out by Sartorelli et al. (2003) the Ca:P ratio of the MBM samples in this study closely agree with the 2.2 as defined by Scott and Dean (1991). As percent ash increased, GE decreased which is in agreement with the observation of Wang and Parsons (1998) reported.

The variability in chemical composition of these MBM samples may be due to the effects of location, processing methods (Wang and Parsons, 1998) and or the source of the MBM (Kirstein, 1999) which invariably would influence its digestibility when included in the diets of monogastric animals (Parsons et al., 1997; Wang and Parsons, 1998; Kirstein, 1999). It is important to note that the variability reported in this study should not be interpreted as reflecting what is in the industry. These MBM samples were deliberately chosen for the purpose of this study. The variation in individual chemical components of MBM alone accounted for only a small and insignificant proportion of the variability in the ME or ME_n. Coefficient of determination for these equations (1 to 6, Table 9) were between 0.032 and 0.470, and therefore not reliable.

When dealing with monogastric animal nutrition, energy is quantitatively the most important item in their diets. The energy needs of monogastric animals form the cornerstone of their diet formulation (Ewan, 2001). Metabolizable energy is the standard way to evaluate feed ingredients. It is the ME that the animal uses for maintenance, growth and production purpose. It is important to mention that there are a number of factors that could affect energy utilization of feed or a particular feed ingredient in pigs. An excess of amino acids in the diet could result in absorption of more amino acids than required by the animal for protein synthesis. The excess amino acid is deaminated with the N excreted and the carbon skeleton metabolized in cells to generate energy. This process consumes energy. This is one of the reasons diets were formulated to have identical CP values at the 3 levels of MBM inclusion. This means that the energy in a diet having excess protein and a poor amino acid profile are not well utilized by the animal even if such diet is high in GE. This means the importance of balanced protein leads to an efficient use of energy during metabolism. High dietary fat in diets could result in decreased feed intake due to high energy density of the diet. Percent energy utilization in this study irrespective of the level of MBM substitution was about 83 (data not shown). The only notable exceptions were MBM samples 2 and 6 in which there was a linear decrease in energy digestibility. These values fall within the range reported by Shi and Noblet (1993). The diets ME_n showed that most of the pigs retained N. This is an indication of the fact that the energy supplied by the MBM is as well utilized as that in the basal diet (C-SBM based).

The variation in the ME and ME_n values of the MBM is of importance when determining the quantity of MBM to be included in the diet. Apparent ME value in this study ranged between 1,569 and 3,308 kcal / kg. The ME_n had a range of between 1,474 and 3,361 kcal / kg. These values are close Shi and Noblet (1993) reported for growing pigs (2,175 kcal / kg). Batterham et al. (1980) reported that the best relationship between DE of MBM and the chemical constituents of the MBM resulted from a combination of GE, CF, Ca and P while the use of GE or CP and CF also gave reliable values. However, they also observed that the difference in MBM digestibility could not be accounted for solely by the variation in the chemical constituents of the MBM. From the data Wang and Parsons (1998) reported, it is expected that MBM sample 2 would give a higher ME and ME_n than that given by MBM sample 1 (because of higher GE and lower ash content). However, the opposite was the case in this study. An explanation for the low ME value of MBM sample 2 could be as a result of the poor quality of the MBM sample as pigs on diets containing this particular MBM had significantly lower DE and energy digestibility resulting in low ME and ME_n of the diets. The contribution of MBM sample 2 to diet ME was relatively smaller relative to the other MBM samples. Pigs on eight of the twelve MBM samples retained N as it is reflected in the lower ME_n values obtained. An excess of amino acids above requirement leads to energy being inefficiently used. Also, poor amino acid profile (as a result of source or processing techniques of the MBM) may affect energy digestibility negatively. Pigs on 8 of the 12 MBM samples retained N resulting in the relative decrease in the values of ME_n. Having all of these nutrients in required ratio and quality is a key to optimizing the energy content of MBM in pig.

A number of factors may be responsible for the observed poor and insignificant correlation between ME or ME_n and chemical components of the MBM samples. The level of fiber in the MBM samples which may be up to 2% (Shi and Noblet, 1993) and the proportion of the ratio of saturated to unsaturated fatty acids may play an important role especially as it affects fat absorption (Atteh and Leeson, 1984 and Leeson and Summers, 2001). The susceptibility of fat to oxidative damage is a function of the saturation level of the fat with unsaturated fat with multiple double bonds being much more susceptible. The likelihood of this process occurring prior to and during processing and storage is high. The longer the period before processing, the higher the probability of oxidative process taking place. High levels of metals like iron from hemoglobin can contribute to the production of reactive oxygen species. These metal contaminants may significantly accelerate the oxidation reaction. To prevent against oxidative injury, the use of antioxidants like ethoxyquin at the very early stages of processing is important. This would lead to a reduction in fatty acid oxidation hence a reduction in the generation of reactive oxygen species.

Prolonged thermal and oxidative exposure increased peroxide values of fats from 1 to 105 mEq/kg (DeRouchey et al., 2004). Biogenic amines including cadavarine, histamine, putrescine, spermidine, and spermine, formed by microbial decarboxylation of amino acids in a variety of animal protein products, are between 39 and 450 mg/kg in MBM (Barnes et al., 2001). Although they were not measured in the current studies, the roles of peroxides and biogenic amines in utilization of energy in MBM and their relationships to ME deserve investigation. The results presented in this study reveal that the GE or CP or CF of the MBM alone is not directly proportional to the ME or ME_n of the MBM but that the interactions between these components of the MBM along with others such as the quality of each MBM sample, quantity of MBM consumed and animal factors interact together to determine the level of the energy in MBM that is metabolized by pigs.

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Table 1. Composition of diets (as-fed basis)

Items		Diets	
	1	2	3
Percent meat and bone meal:	0	5	10
Ingredients, g/kg			
Corn	715	733	750
Soybean Meal	235	180	125
Dicalcium phosphate[a]	16	8	0
Limestone[b]	9	4	0
Salt	3	3	3
Vitamin premix [c]	3	3	3
Selenium premix [d]	0.5	0.5	0.5
Trace mineral premix [e]	1.5	1.5	1.5
Lysine.HCl	1.5	1.5	1.5
Antioxidant[f]	0.5	0.5	0.5
Meat and bone meal	0	50	100
Chromic oxide premix [g]	15	15	15
Total	1,000	1,000	1,000
Calculated nutrients and energy [h]			
Protein, g/kg	170.0	170.2	170.3
DE, kcal/kg	3,431	3,414	3,394
ME, kcal/kg	3,282	3,269	3,252
Ca, g/kg	7.3	8.7	10.6
P, g/kg	6.4	7.1	7.8

[a] Contained 20% Ca, 18.5% P.

[b] Contained 36% Ca.

[c] Provided per g of premix: Vitamin A, 2,440 IU; Vitamin D_3, 243 IU; Vitamin E, 9.3 IU; Vitamin K activity, 1.9 mg; Menadione, 600 µg; Vitamin B_{12}, 12.4 mg; Riboflavin, 2.4 mg; D-Pantothenic acid, 9 mg; Niacin, 14 mg.

[d] Provided 600 µg Se (as sodium selenite) per g of premix.

[e] Provided per g premix: Fe (as $FeSO_4$-H_2O), 179 mg; Mn, (as $MnSO_4$) 60 mg, Zn (as $ZnSO_4$), 150 mg; Cu (as $CuSO_4$), 17.5 mg; I(as $Ca(IO_3)_2$), 3 mg.

[f] Provided 660 mg ethoxyquin per g of premix.

[g] Chromic oxide (Cr_2O_3) premix added as index at a ratio 1:4 of chromic oxide:finely ground corn.

[h] Values depend on the characteristic of each MBM sample. Calculations were based on 100 g / kg Ca and 50 g / kg P in the MBM sample used in the diet template.

Table 2. Nutrient and energy composition of meat and bone meal (MBM) samples[a]

MBM Sample number	DM g/kg	CP g/kg[b]	Crude Fat g/kg	Phosphorus g/kg	Calcium g/kg	Ash g/kg	GE kcal/kg[c]
1	921.2	496.7	91.1	61.7	145.8	381.9	3,493
2	963.7	512.4	97.7	46.5	106.4	317.4	3,881
3	945.1	564.2	110.8	28.3	61.6	232.3	4,469
4	939.9	538.0	140.8	25.6	54.3	200.3	4,661
5	962.3	549.1	110.3	40.8	93.5	279.6	4,107
6	982.1	619.1	96.9	26.7	61.6	202.7	4,732
7	979.3	542.5	93.3	43.4	102.5	291.2	4,155
8	990.7	537.5	115.5	39.4	88.0	261.4	4,342
9	989.4	535.7	106.5	36.1	84.3	248.2	4,320
10	971.9	525.4	120.5	36.8	85.1	250.3	4,377
11	973.4	604.8	113.4	27.4	66.3	213.0	4,671
12	969.2	537.2	151.2	37.6	87.2	261.2	4,490

[a] Values are means of triplicates analyses expressed on DM basis.

[b] Crude protein, CP = Nitrogen*6.25.

[c] Gross energy.

Table 3. Amino acid composition (%) of the 12 samples of meat and bone meal (air-dry basis)

	Meat and bone meal sample number											
	1	2	3	4	5	6	7	8	9	10	11	12
Alanine	3.45	3.57	3.59	3.26	3.45	3.82	3.67	3.56	3.61	3.38	4.07	3.53
Arginine	3.21	3.33	3.39	3.32	3.54	4.05	3.65	3.69	3.62	3.35	3.78	3.55
Aspartic Acid	3.15	3.37	3.98	3.85	3.91	4.56	3.83	3.95	3.76	3.72	4.47	3.96
Cysteine	0.31	0.27	0.43	0.47	0.49	0.86	0.49	0.58	0.41	0.47	0.55	0.45
Glutamic Acid	5.49	5.90	7.33	6.60	6.53	7.80	6.68	6.96	6.52	6.47	7.42	6.51
Glycine	7.10	6.83	5.92	5.40	6.02	6.40	7.06	6.76	7.02	6.27	6.60	6.18
Histidine	0.76	0.91	1.29	1.17	1.21	1.32	0.99	1.05	0.96	1.05	1.45	1.08
Hydroxylysine	0.39	0.29	0.23	0.23	0.24	0.24	0.31	0.28	0.30	0.24	0.24	0.29
Hydroxyproline	3.31	2.67	2.19	1.96	2.11	2.16	3.01	2.61	2.91	2.49	2.41	2.48
Isoleucine	1.12	1.39	1.79	1.68	1.72	2.15	1.60	1.60	1.57	1.54	1.94	1.69
Lanthionine	0.03	0.08	0.05	0.04	0.06	0.14	0.05	0.13	0.04	0.05	0.09	0.06
Leucine	2.56	2.81	3.43	3.38	3.36	4.17	3.20	3.30	3.19	3.15	4.06	3.31
Lysine	2.32	2.31	3.17	2.83	3.08	3.15	2.84	2.82	2.73	2.64	3.29	2.91
Methionine	0.55	0.50	0.66	0.69	0.79	0.84	0.81	0.82	0.72	0.66	0.82	0.83
Ornithine	0.04	0.06	0.10	0.07	0.02	0.11	0.02	0.07	0.07	0.06	0.11	0.07
Phenylalanine	1.38	1.52	1.81	1.74	1.78	2.25	1.70	1.75	1.70	1.72	2.16	1.78
Proline	4.24	4.06	3.78	3.44	3.63	4.47	4.24	4.16	4.24	3.96	4.28	3.84
Serine	1.68	1.44	1.75	1.78	1.59	2.69	1.93	1.99	1.81	1.91	2.21	1.77
Taurine	0.03	0.05	0.07	0.07	0.10	0.09	0.17	0.07	0.08	0.09	0.19	0.14
Threonine	1.37	1.39	1.72	1.73	1.68	2.18	1.69	1.75	1.62	1.64	2.02	1.76
Tryptophan	0.33	0.32	0.42	0.41	0.43	0.47	0.39	0.38	0.37	0.36	0.47	0.40
Tyrosine	0.88	0.97	1.29	1.22	1.19	1.54	1.16	1.27	1.15	1.17	1.42	1.21
Valine	1.76	2.10	2.49	2.33	2.36	3.07	2.25	2.35	2.28	2.23	2.84	2.30
Total	45.46	46.14	50.88	47.67	49.29	58.53	51.74	51.9	50.68	48.62	56.89	50.10

Table 4. Five-day meat and bone meal (MBM) intake by growing pigs fed diets containing 0, 5, or 10 % MBM from different sources

	Meat and bone meal intake, kg [a]			
MBM sample number	0 % MBM	5 % MBM	10 % MBM	SD
1[b]	0.00	0.374	0.713	0.0450
2[b]	0.00	0.378	0.708	0.0430
3[b]	0.00	0.344	0.629	0.0413
4[b]	0.00	0.369	0.760	0.0391
5[b]	0.00	0.350	0.666	0.0498
6[bc]	0.00	0.381	0.676	0.0441
7[b]	0.00	0.354	0.616	0.0676
8[b]	0.00	0.284	0.556	0.0628
9[b]	0.00	0.333	0.599	0.0365
10[b]	0.00	0.296	0.599	0.0430
11[b]	0.00	0.351	0.688	0.0320
12[b]	0.00	0.323	0.634	0.0310

[a] Values are least square means of 8 pigs per treatment.

[b] Linear effect of meat and bone meal $P < 0.05$.

[c] Quadratic effect of meat and bone meal $P < 0.05$.

Table 5. Five-day meat and bone meal (MBM) contribution to metabolizable energy intake of diets in growing pigs fed diets containing 0, 5, or 10 % MBM from different sources

	Meat and bone meal contribution to ME intake, kcal [a]			
MBM sample number	0 % MBM	5 % MBM	10 % MBM	SD
1 [bc]	0.00	1,481	1,988	320.4
2 [b]	0.00	816	1,095	322.7
3 [b]	0.00	968	2,029	295.7
4 [b]	0.00	1,000	2,428	387.1
5 [b]	0.00	1,426	1,698	355.4
6 [bc]	0.00	1,260	1,786	325.7
7 [b]	0.00	968	1,277	509.1
8 [b]	0.00	824	1,856	251.3
9 [bc]	0.00	1,356	1,631	544.7
10 [b]	0.00	1,235	2,016	355.7
11 [b]	0.00	1,063	1,909	305.9
12 [b]	0.00	1,166	1,638	341.8

[a] Values are least square means of 8 pigs per treatment.

[b] Linear effect of meat and bone meal $P < 0.05$.

[c] Quadratic effect of meat and bone meal $P < 0.05$.

Table 6. Five-day meat and bone meal (MBM) contribution to nitrogen-corrected metabolizable energy (ME_n) of diets in growing pigs fed diets containing 0, 5, or 10 % MBM from different sources

	Meat and bone meal contribution to ME_n intake, kcal [a]			
MBM sample number	0 % MBM	5 % MBM	10 % MBM	SD
1 [bc]	0.00	1,486	1,946	289.7
2 [b]	0.00	708	1,024	301.3
3 [b]	0.00	924	1,854	276.6
4 [b]	0.00	1,227	2,588	344.9
5 [b]	0.00	1,246	1,521	338.5
6 [bc]	0.00	1,356	1,745	295.9
7 [b]	0.00	764	1,182	492.9
8 [b]	0.00	828	1,763	292.6
9 [bc]	0.00	1,305	1,627	477.8
10 [b]	0.00	1,275	2,046	352.5
11 [b]	0.00	984	1,965	290.6
12 [b]	0.00	1,107	1,910	321.2

[a] Values are least square means of 8 pigs per treatment.

[b] Linear effect of meat and bone meal $P < 0.05$.

[c] Quadratic effect of meat and bone meal $P < 0.05$.

Table 7. Apparent metabolizable energy (ME) and nitrogen-corrected metabolizable energy (ME_n) of twelve samples of meat and bone meal (MBM)

MBM sample number	ME kcal/kg DM	SE	ME_n kcal/kg DM	SE
1	2,821	256	2,758	252
2	1,569	230	1,474	216
3	3,205	232	2,922	224
4	3,157	275	3,359	247
5	2,584	324	2,312	294
6	2,697	222	2,643	240
7	2,232	328	2,051	311
8	3,163	306	3,029	305
9	2,727	203	2,719	194
10	3,308	329	3,361	328
11	2,786	216	2,853	202
12	2,587	292	3,004	246

Table 8. Pearson's correlation coefficients between components of the 10 samples of meat and bone meal[a]

	ME	ME_n	GE	CP	Crude fat	Phosphorus	Calcium
ME_n	0.853						
P-value	0.001						
GE	0.336	0.541					
P-value	0.342	0.106					
CP	-0.177	-0.222	0.613				
P-value	0.624	0.538	0.059				
Crude fat	0.323	0.686	0.295	-0.405			
P-value	0.363	0.029	0.409	0.245			
Phosphorus	-0.432	-0.472	-0.902	-0.612	-0.148		
P-value	0.212	0.168	< 0.001	0.059	0.683		
Calcium	-0.511	-0.523	-0.871	-0.532	-0.196	0.989	
P-value	0.131	0.121	0.001	0.113	0.588	< 0.001	
Ash	-0.453	-0.536	-0.933	-0.585	-0.166	0.974	0.960
P-value	0.188	0.111	< 0.001	0.076	0.647	< 0.001	< 0.001

[a] Sample numbers 1 and 2 were excluded from the analyses; ME = Metabolizable energy, ME_n = Nitrogen-corrected metabolizable energy, CP = Crude protein (N * 6.25), GE = Gross energy.

Table 9. Intercept, regression coefficients, coefficient of determination, and standard deviation of the equations relating metabolizable energy (ME) and nitrogen-corrected metabolizable energy (ME$_n$) to components of meat and bone meal[a]

		Regression coefficients							
	Intercept	GE	CP	CF	P	Ca	Ash	SD	R^2
ME Equations									
1	413	0.549						348	0.112
2	3,929		-1.951					364	0.032
3	2,119			6.256				350	0.104
4	3,629				-22.918			333	0.187
5	3,709					-11.019		318	0.261
6	4,072						-5.033	239	0.206
7	6,982	0.283	-6.26	-3.75	129.47	-54.91	-6.57	376	0.612
8	4,902	0.748	-7.45	-5.47	108.7	-55.1		329	0.603
9	11,858	-0.341	-7.89	-1.65			-12.01	324	0.520
10	1,444	1.162	-6.76					319	0.348
11	12,316	-0.556	-7.03				-12.71	296	0.518
12	10,561		-8.69	-2.95			-10.44	296	0.518
13	9,254		-7.41				-9.41	278	0.504
14	3,386			4.94			-4.56	338	0.269
15	7,667		-6.02	-2.40	74.14	-47.62		302	0.582
16	6,576		-4.85		82.48	-49.23		279	0.573
17	3,050			1.69	162.1	-75.81		300	0.504
ME$_n$ Equations									
1	-1,858	1.057						372	0.293
2	4,446		-2.918					431	0.049
3	983			15.889				322	0.470
4	3,850				-29.954			390	0.223
5	3,883					-13.482		377	0.273
6	4,561						-7.113	373	0.287
7	3,937	1.089	-8.74	3.58	60.89	-15.92	-9.57	314	0.811
8	906	1.766	-10.47	1.07	30.62	-16.16		281	0.798
9	4,532	1.116	-10.13	3.12			-5.71	248	0.803
10	-79.43	2.117	-11.66					220	0.784
11	3,664	1.525	-11.76				-4.38	230	0.798
12	8,780		-7.50	-7.41			-10.84	238	0.783
13	12,504		-10.71				-13.44	249	0.723
14	2,583			14.22			-5.76	278	0.653
15	7,434		-7.10	8.33	-51.02	1.43		298	0.717
16	11,219		-11.18		7.00	-79.96		305	0.642
17	1,993			13.15	52.65	-31.78		306	0.641

[a] Sample numbers 1 and 2 were excluded from the analyses; ME = Metabolizable energy (kcal/kg), ME$_n$ = Nitrogen-corrected metabolizable energy (kcal/kg), GE = Gross energy (kcal/kg), CP = Crude protein (N * 6.25, g/kg), CF = Crude fat (g/kg), P = Phosphorus (g/kg), Ca = Calcium (g/kg), Ash = Ash (g/kg).