FINAL REPORT

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Title: 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 results of these analyses are shown in the summary Table on the next page (Page 3). 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 ME_n of the 12 MBM samples ranged between 1,585 and 3,345 and 1,529 and 3,395 kcal / kg dry matter.

The regression equations relating ME or ME_n to the chemical components are: $ME = 7872 - 0.39\ GE - 3.39\ CP + 3.39\ CF - 7.52\ Ash$ ($r^2 = 0.23$); $ME = -1074 + 1.29\ GE - 4.16\ CP - 1.16\ CF - 25.16\ Ca + 76.16\ P$ ($r^2 = 0.22$); $ME = 6894 + 0.04\ GE - 5.11\ CP - 5.96\ Ash$ ($r^2 = 0.23$); $ME = 6345 - 4.30\ CP + 1.85\ CF - 5.57\ Ash$ ($r^2 = 0.23$); $ME_n = 5108 + 0.20\ GE - 5.01\ CP + 6.18\ CF - 4.74\ Ash$ ($r^2 = 0.37$); $ME_n = -1513 + 1.64\ GE - 7.06\ CP + 2.27\ CF + 7.17\ Ca + 1.7\ P$ ($r^2 = 0.37$); $ME_n = 3325 + 1.00\ GE - 8.15\ CP - 1.88\ Ash$ ($r^2 = 0.36$); $ME_n = 5896 - 4.54\ CP + 6.97\ CF - 5.74\ Ash$ ($r^2 = 0.37$).

When the first two MBM samples were removed from the data pool, the correlation coefficient between MBM AME_n and CF ($r = 0.55$, $P < 0.1$) and ash ($r = -0.57$, $P < 0.1$) became significant. The overall regression equations for the remaining ten MBM samples (Table 13) were: $AME = 12050 - 0.33\ GE - 8.23\ CP - 2.49\ CF - 11.85\ Ash$ ($r^2 = 0.54$); $AME = 6139 + 0.64\ GE - 8.32\ CP - 6.01\ CF - 42.91\ Ca + 74.79\ P$ ($r^2 = 0.59$); $AME = 12744 - 0.65\ GE - 6.93\ CP - 12.91\ Ash$ ($r^2 = 0.53$); $AME = 10805 - 9.00\ CP - 3.75\ CF - 10.34\ Ash$ ($r^2 = 0.53$); $AME_n = 8182 + 0.70\ GE - 11.01\ CP - 0.75\ CF - 9.33\ Ash$ ($r^2 = 0.77$); $AME_n = 3796 + 1.58\ GE - 12.32\ CP - 3.67\ CF - 9.39\ Ca + 0.83\ P$ ($r^2 = 0.74$); $AME_n = 8391 + 0.60\ GE - 10.61\ CP - 9.66\ Ash$ ($r^2 = 0.76$); $AME_n = 10838 - 9.36\ CP + 1.92\ CF - 12.55\ Ash$ ($r^2 = 0.76$).

Summary of nutrient and energy of meat and bone meal used in the study

Meat & bone meal Sample ID	Dry Matter, g/kg	Crude protein, g/kg	Crude Fat, g/kg	Phosphorus, g/kg	Calcium, g/kg	Ash, g/kg	Gross Energy, kcal/kg	Metabolizable Energy (ME), kcal/kg	MEn, kcal/kg
A1-02 1	921.2	496.7	91.1	61.7	145.8	381.9	3,493	2,860	2,785
A1-02 2	963.7	512.4	97.7	46.5	106.4	317.4	3,881	1,585	1,529
A1-02 3	945.1	564.2	110.8	28.3	61.6	232.3	4,469	3,199	2,909
A1-02 4	939.9	538	140.8	25.6	54.3	200.3	4,661	3,138	3,329
A1-02 5	962.3	549.1	110.3	40.8	93.5	279.6	4,107	2,594	2,327
A1-02 6	982.1	619.1	96.9	26.7	61.6	202.7	4,732	2,690	2,645
A1-02 7	979.3	542.5	93.3	43.4	102.5	291.2	4,155	2,280	2,093
A1-02 8	990.7	537.5	115.5	39.4	88	261.4	4,342	3,105	2,975
A1-02 9	989.4	535.7	106.5	36.1	84.3	248.2	4,320	2,762	2,742
A1-02 10	971.9	525.4	120.5	36.8	85.1	250.3	4,377	3,345	3,395
A1-02 11	973.4	604.8	113.4	27.4	66.3	213	4,671	2,782	2,844
A1-02 12	969.2	537.2	151.2	37.6	87.2	261.2	4,490	2,582	2,752

ME = Metabolizable energy; ME_n = Metabolizable energy corrected for nitrogen; GE = Gross energy; CP = Crude protein; CF = Crude fat; Ash; Ca = Calcium; P = Phosphorus; MBM = Meat and bone meal.

For samples 1 to 12: $ME = 7872 - 0.39\ GE - 3.39\ CP + 3.39\ CF - 7.52\ Ash$ $(r^2 = 0.23)$.
$ME = -1074 + 1.29\ GE - 4.16\ CP - 1.16\ CF - 25.16\ Ca + 76.16\ P$ $(r^2 = 0.22)$.
$ME = 6894 + 0.04\ GE - 5.11\ CP - 5.96\ Ash$ $(r^2 = 0.23)$; $ME = 6345 - 4.30\ CP + 1.85\ CF - 5.57\ Ash$ $(r^2 = 0.23)$.
$ME_n = 5108 + 0.20\ GE - 5.01\ CP + 6.18\ CF - 4.74\ Ash$ $(r^2 = 0.37)$.
$ME_n = -1513 + 1.64\ GE - 7.06\ CP + 2.27\ CF + 7.17\ Ca + 1.7\ P$ $(r^2 = 0.37)$.
$ME_n = 3325 + 1.00\ GE - 8.15\ CP - 1.88\ Ash$ $(r^2 = 0.36)$; $ME_n = 5896 - 4.54\ CP + 6.97\ CF - 5.74\ Ash$ $(r^2 = 0.37)$.

For samples 3 to 12: $ME = 12050 - 0.33\ GE - 8.23\ CP - 2.49\ CF - 11.85\ Ash$ $(r^2 = 0.54)$.
$ME = 6139 + 0.64\ GE - 8.32\ CP - 6.01\ CF - 42.91\ Ca + 74.79\ P$ $(r^2 = 0.59)$.
$ME = 12744 - 0.65\ GE - 6.93\ CP - 12.91\ Ash$ $(r^2 = 0.53)$; $ME = 10805 - 9.00\ CP - 3.75\ CF - 10.34\ Ash$ $(r^2 = 0.53)$.
$ME_n = 8182 + 0.70\ GE - 11.01\ CP - 0.75\ CF - 9.33\ Ash$ $(r^2 = 0.77)$.
$ME_n = 3796 + 1.58\ GE - 12.32\ CP - 3.67\ CF - 9.39\ Ca + 0.83\ P$ $(r^2 = 0.74)$.
$ME_n = 8391 + 0.60\ GE - 10.61\ CP - 9.66\ Ash$ $(r^2 = 0.76)$; $ME_n = 10838 - 9.36\ CP + 1.92\ CF - 12.55\ Ash$ $(r^2 = 0.76)$.

Summary

The apparent metabolizable energy (AME) and AME corrected for nitrogen (AME_n) values of 12 samples of meat and bone meal (MBM) were determined using 288 barrows with an average weight of 35 kg. Diets were formulated by replacing 0, 1.8, or 3.5 % corn and 0, 5.5, or 11 % soybean meal (SBM) with 0, 5, or 10 % MBM, respectively, in a basal corn-soybean meal diet with each of the 12 samples of MBM. The calculated crude protein (CP) and digestible energy (DE) of the basal diets (0 % MBM) were 17.0 % and 3,431 kcal / kg, respectively. Each diet was fed to 8 barrows in individual metabolism crates in a digestibility assay 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), and ash contents of the MBM samples on a dry matter basis ranged from 3,493 to 4,732 kcal / kg, 49.67 to 61.91 %, 9.11 to 15.12 %, and 20.03 to 38.19 %, respectively. The AME and AME_n content of each of the MBM sample was calculated from the slope of the regression of MBM contribution to AME and AME_n intake, respectively, against amount of MBM intake. The AME and AME_n of the 12 MBM samples ranged between 1,585 and 3,345 and 1,529 and 3,395 kcal / kg dry matter. For the 12 MBM samples, MBM intake and MBM contribution to AME and AME_n increased linearly ($P < 0.05$) with increasing level of MBM in the diets. The metabolizable energy (ME) and nitrogen-corrected metabolizable ME_n of the 12 MBM samples ranged between 1,585 and 3,345 and 1,529 and 3,395 kcal / kg dry matter. The regression equations relating ME or ME_n to the chemical components are: $ME = 7872 - 0.39\ GE - 3.39\ CP + 3.39\ CF - 7.52\ Ash$ ($r^2 = 0.23$); $ME = -1074 + 1.29\ GE - 4.16\ CP - 1.16\ CF - 25.16\ Ca + 76.16\ P$ ($r^2 = 0.22$); $ME = 6894 + 0.04\ GE - 5.11\ CP - 5.96\ Ash$ ($r^2 = 0.23$); $ME = 6345 - 4.30\ CP + 1.85\ CF - 5.57\ Ash$ ($r^2 = 0.23$); $ME_n = 5108 + 0.20\ GE - 5.01\ CP + 6.18\ CF - 4.74\ Ash$ ($r^2 = 0.37$); $ME_n = -1513 + 1.64\ GE - 7.06\ CP + 2.27\ CF + 7.17\ Ca + 1.7\ P$ ($r^2 = 0.37$); $ME_n = 3325 + 1.00\ GE - 8.15\ CP - 1.88\ Ash$ ($r^2 = 0.36$); $ME_n = 5896 - 4.54\ CP + 6.97\ CF - 5.74\ Ash$ ($r^2 = 0.37$). These results show that energy of MBM is related to its chemical attributes and MBM can be a good source of energy by replacing up to 10 % of corn and SBM in growing pigs' diet.

Introduction

Meat and bone meal has been used extensively in the diets of monogastric animals as a source of CP. The importance of MBM as a source of energy for pigs rests partially on the abundance of MBM in the USA as well as its high GE content. The nutrient composition of MBM has been reported to vary widely (Dale, 1997; Shirley and Parsons, 2001; Hendriks, 2004). Thus its inclusion in diets has a lot of implications on the digestibility of energy and other nutrients and the palatability of the diet

(Martosiswoyo and Jensen, 1988; Larbier and Leclercq, 1994). The DE content of 14 meat meals and MBM was estimated in growing pigs in Australia by Batterham et al. (1980). They reported DE values between 2,247 and 3,322 kcal / kg (on air dry basis). These large variations were attributed to the ether extract, bone and chemical content of the meals. In addition to this, Batterham et al. (1980) related the DE to GE, ether extract, Ca and P or GE alone or CP and ether extract. However, the ME content of the MBM was not determined in the study reported by Batterham et al. (1980). In another study by Shi and Noblet (1993), the DE and ME values of MBM in complex diets were found to be higher in sows compared with growing pigs. The DE of MBM when fed to sows and growing pigs were estimated to range between 3,439 and 3,824 and 2,858 and 3,616 kcal / kg dry matter, respectively (Shi and Noblet, 1993). The ME values in the same animals were from 3,136 to 3,597 for sows and 2,758 and 3,511 kcal / kg for growing pigs on dry mater basis. The growing pigs used in the study conducted by Shi and Noblet (1980) were fed at nearly ad libitum in contrast to restricted feeding used to estimate values in most feeding tables. The results from their study showed that DE and ME of a feedstuff are dependent not only on the chemical composition of the MBM itself but also on the physiological stage of the animals, age, body weight and feeding levels. 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 accurately determining the ME values of MBM becomes evident when one considers the fact that energy is the most expensive component of swine diet. The effects of the variation in the chemical composition of each MBM sample on the AME and AME_n of the MBM was evaluated.

The objective of this study was to determine the AME and AME_n for pigs in 12 samples of MBM and to assess the variation in AME and AME_n of these MBM samples and develop regression equations that relate the variation to chemical composition of the MBM to their AME and AME_n.

Materials and Methods

Meat and bone meal samples

Twenty-four samples of MBM were selected from different areas of the United States and analyzed for proximate composition. Twelve samples, deliberately selected to represent a wide range of chemical composition, were used in these experiments to determine the energy value for pigs. The AME and AME_n of diets and MBM samples were determined using total collection method.

Diet formulation

Due to the consideration that ME values are extremely difficult to determine directly using MBM as the sole source of dietary energy, diets were formulated to replace portions of corn and SBM of a basal diet with MBM. Thus the indirect method of ME determination was employed in this study. To minimize the negative impact of excess nitrogen (N) on ME a design in which all the three diets had comparable CP value (170 g / kg) was used. Diets were formulated by replacing 0, 1.8, or 3.5 % corn and 0, 5.5, or 11 % SBM with 0, 5, or 10 % MBM, respectively, in a basal corn-soybean meal diet with each of the 12 samples of MBM (Table 7). 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 & Use Committee approved all animal care and handling procedures used in this study. Two hundred and eighty eight Yorkshire-Landrace barrows, with an average weight of 35 kg, were used in this study. The basal diet was a C-SBM based diet with 0 % MBM. Twelve MBM samples were evaluated for their AME and AME_n. Each diet was fed to 8 barrows in individual metabolism crate in a digestibility assay that employed a 5-d acclimation followed by a 5-d period of total but separate collection of feces and urine.

Feeding and fecal collection

The experiment had a 5-d adjustment and 5 d of total but separate collection of orts, feces and urine with ferric oxide serving as the indigestible marker as described previously by Adeola and Bajallieh (1997). The 5-d adjustment period allowed the barrows to 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 marker. Upon the appearance of the marker in the feces, fecal collection was terminated. Feces were collected once daily weighed and stored at -4 ^{0}C. Urine was collected at the time of feces collection, measured in a graduated cylinder and a 25 % 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 ^{0}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 ^{0}C followed by ashing in a muffle furnace for 18 h at 600 ^{0}C.

The frozen feces were thawed (the entire collection for each pig was pooled), placed in aluminum pan, weighed and dried at 55 ^{0}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 ^{0}C, weighed and stored in Whirl-Pak bags at -18 ^{0}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

Metabolizable energy of the basal diet (ME_{BD}) is contributed by 0.715 corn (C) and 0.235 soybean meal (SBM).

Thus:

$$ME_{BD} = 0.715\ C + 0.235\ SBM \qquad [Eqn\ 1]$$

The ME contents of C and SBM are 3,420 and 3,385 kcal/kg (NRC, 1998), respectively.

Thus:

$$C/SBM = 3420/3385$$

$$C = 3420\ SBM / 3385 \qquad [Eqn\ 2]$$

$$SBM = 3385\ C / 3420 \qquad [Eqn\ 3]$$

Substituting Eqn 2 in Eqn 1 gives: $ME_{BD} = (0.715 * 3420 / 3385\ SBM) + 0.235\ SBM$;

$$SBM = ME_{BD} / 0.9574 \qquad [Eqn\ 4]$$

Substituting Eqn 3 in Eqn 1 gives: $ME_{BD} = 0.715\ C + (0.235 * 3385 / 3420\ C)$

$$C = ME_{BD} / 0.9476 \qquad [Eqn\ 5]$$

Metabolizable energy of the diet containing 5 % MBM (ME_{MBM1}) is contributed by 0.733 C, 0.180 SBM and 0.05 MBM.

Thus:

$$ME_{MBM1} = 0.733\ C + 0.180\ SBM + 0.05\ MBM \qquad [Eqn\ 6]$$

Substituting Eqn 4 and 5 in Eqn 6 gives:

$$ME_{MBM1} = [0.733(ME_{BD} / 0.9476] + [0.180 * (ME_{BD} / 0.9574)] + 0.05\ MBM$$

$$MBM = (ME_{MBM1} - 0.96154\ ME_{BD}) / 0.05 \qquad [Eqn\ 7]$$

Metabolizable energy of the diet containing 10 % MBM (ME_{MBM2}) is contributed by 0.750 C, 0.125 SBM, and 0.10 MBM. Thus:

$$ME_{MBM2} = 0.750\ C + 0.125\ SBM + 0.1\ MBM \qquad [Eqn\ 8]$$

Substituting Eqn 4 and 5 in Eqn 8 gives:

$$ME_{MBM2} = [0.750\ (ME_{BD} / 0.9476)] + [0.125 * (ME_{BD} / 0.9574)] + 0.1\ MBM$$

$$MBM = (ME_{MBM2} - 0.92203\ ME_{BD}) / 0.1 \qquad [Eqn\ 9]$$

Meat and bone meal intake of pigs fed the basal diet is zero

Meat and bone meal intake of pigs fed the diet containing 5 % MBM is:

0.05 x feed intake in kg [Eqn 10]

Meat and bone meal intake of pigs fed the diet containing 10 % MBM is:

0.1 x feed intake in kg [Eqn 11]

Meat and bone meal contribution to ME intake of pigs fed the basal diet is zero.

Meat and bone meal contribution to ME intake of pigs fed the diet containing 5 % MBM is Eqn 7 multiplied by Eqn 10.

Meat and bone meal contribution to ME intake of pigs fed the diet containing 10 % MBM is Eqn 9 multiplied by Eqn 11.

Replacement of the same ratio of corn and SBM by MBM in diets containing 0, 5, or 10 % MBM formed the basis for equations 1 to 11. The ME content of the diet was calculated as the difference between energy in the diet intake and the sum total of energy in the orts, feces, and urine.

Statistical analysis

Meat and bone meal contribution to AME or AME_n intake in kilocalories was regressed against kilograms of MBM intake for each MBM sample using the PROC REG of SAS® (SAS Institute, 2002). The slope of the regression gave the AME or AME_n content of the MBM sample. Multiple linear regression (stepwise procedure) analyses were carried out by regressing MBM AME or MBM AME_n on the analyzed chemical constituents of the MBM samples.

The data for each MBM sample was analyzed as a randomized complete block design of 3 treatments in 8 blocks, using the General Linear Models of SAS® (SAS institute, 2002). Orthogonal polynomial contrast using linear and quadratic effects was used to compare the treatment means.

Results

The chemical compositions of the twelve MBM samples are shown in Table 2. The dry matter contents ranged between 92 and 99 %. Crude protein values were between 50 and 62 % and CF was between 9 and 15 %. Calcium and P values range between 5 and 15 % and 3 and 6 %, respectively. Percent ash ranged from 20 to 38 with GE values between 3,495 and 4,732 kcal/kg. The amino acid composition of the 12 samples of MBM is as shown in Table 3. The results from the analysis (Tables 2 and 3) show that MBM sample 6 and 11 have a higher CP content but those of MBM samples 1 and 2 were relatively low.

The GE values and fat content of the diets are as show in Table 4. There was an increase in diet GE (except for the GE for MBM sample 1) and fat content with increase in MBM substitution. The DE of the diets (Table 5) ranged from 3,359 to 3,773 kcal / kg dry matter. As the MBM sample 2 in the diets increased linearly, there was a linear decrease ($P < 0.05$) in DE.

Percent energy digestibility is reported in Table 6 with a range between 81 and 86 %. Linear decrease ($P < 0.05$) was observed in energy digestibility with linear increase in MBM samples 2 and 6 in the diets. A linear decrease ($P < 0.05$) in diets AME was observed for MBM sample 2 as the MBM contents of diets increased (Table 7). Meat and bone meal samples 5 and 6 when substituted for corn and SBM in the diets resulted in a quadratic effects ($P < 0.05$) and ($P < 0.1$), respectively, in diet AME. When AME of the diets was corrected for N (AME_n), the inclusion of MBM samples 2 and 4 resulted in a decrease ($P < 0.05$) and an increase ($P < 0.1$) in AME_n, respectively (Table 8).

Meat and bone meal intake of pigs increased linearly ($P < 0.05$) with linear increase in MBM inclusion in the diet for the 12 MBM samples. Quadratic effects ($P < 0.05$) and ($P < 0.1$), respectively, were also observed for MBM samples 6 and 9 (Table 9). The contribution of MBM to AME and AME_n of the diets is as shown in Table 10. The inclusion of 12 MBM samples resulted in linear increase ($P < 0.05$) in contribution to AME and AME_n.

The AME and AME_n of 12 samples of MBM as derived from the slope of the regression of MBM contribution to diet AME and AME_n on MBM intake are as shown in Table 11. The AME values ranged from 1,585 to 3,345 kcal / kg, respectively, with an overall mean of 2,744 kcal / kg. A range between 1,529 and 3,395 kcal /kg with a mean of 2,694 kcal /kg was obtained when nitrogen was corrected for (AME_n). The correlation coefficients of the 12 MBM samples (Table 12) show that there is significant correlation between MBM GE and CP (0.75, $P = 0.005$), and CF (0.53, $P < 0.08$). Calcium (-0.95) and P (-0.96) were negatively correlated ($P < 0.0001$) with MBM GE.
The influence of the chemical constituents of the twelve MBM samples on the AME and AME_n of the MBM samples is shown in Table 12 with GE, CP and CF having positive ($P > 0.1$) correlation coefficients. Only CF had a significant correlation with the AME_n. Overall Regression Equation: $\text{AME} = 7872 - 0.39\ \text{GE} - 3.39\ \text{CP} + 3.39\ \text{CF} - 7.52\ \text{Ash}$ ($r^2 = 0.23$); $\text{AME} = -1074 + 1.29\ \text{GE} - 4.16\ \text{CP} - 1.16\ \text{CF} - 25.16\ \text{Ca} + 76.16\ \text{P}$ ($r^2 = 0.22$); $\text{AME} = 6894 + 0.04\ \text{GE} - 5.11\ \text{CP} - 5.96\ \text{Ash}$ ($r^2 = 0.23$); $\text{AME} = 6345 - 4.30\ \text{CP} + 1.85\ \text{CF} - 5.57\ \text{Ash}$ ($r^2 = 0.23$); $\text{AME}_n = 5108 + 0.20\ \text{GE} - 5.01\ \text{CP} + 6.18\ \text{CF} - 4.74\ \text{Ash}$ ($r^2 = 0.37$); $\text{AME}_n = -1513 + 1.64\ \text{GE} - 7.06\ \text{CP} + 2.27\ \text{CF} + 7.17\ \text{Ca} + 1.7\ \text{P}$ ($r^2 = 0.37$); $\text{AME}_n = 3325 + 1.00\ \text{GE} - 8.15\ \text{CP} - 1.88\ \text{Ash}$ ($r^2 = 0.36$); $\text{AME}_n = 5896 - 4.54\ \text{CP} + 6.97\ \text{CF} - 5.74\ \text{Ash}$ ($r^2 = 0.37$).

When the first two MBM samples were removed from the data pool, the correlation coefficient between MBM AME_n and CF ($r = 0.55$, $P < 0.1$) and ash ($r = -0.57$, $P < 0.1$) became significant. The overall regression equations for the remaining ten MBM samples (Table 13) were: $\text{AME} = 12050 - 0.33\ \text{GE} - 8.23\ \text{CP} - 2.49\ \text{CF} - 11.85\ \text{Ash}$ ($r^2 = 0.54$); $\text{AME} = 6139 + 0.64\ \text{GE} - 8.32\ \text{CP} - 6.01\ \text{CF} - 42.91\ \text{Ca} + 74.79\ \text{P}$ ($r^2 = 0.59$); $\text{AME} = 12744 - 0.65\ \text{GE} - 6.93\ \text{CP} - 12.91\ \text{Ash}$ ($r^2 = 0.53$); $\text{AME} = 10805 - 9.00\ \text{CP} - 3.75\ \text{CF} - 10.34\ \text{Ash}$ ($r^2 = 0.53$); $\text{AME}_n = 8182 + 0.70\ \text{GE} - 11.01\ \text{CP} - 0.75\ \text{CF} - 9.33\ \text{Ash}$ ($r^2 = 0.77$); $\text{AME}_n = 3796 + 1.58\ \text{GE} - 12.32\ \text{CP} - 3.67\ \text{CF} - 9.39\ \text{Ca} + 0.83\ \text{P}$ ($r^2 = 0.74$); $\text{AME}_n = 8391 + 0.60\ \text{GE} - 10.61\ \text{CP} - 9.66\ \text{Ash}$ ($r^2 = 0.76$); $\text{AME}_n = 10838 - 9.36\ \text{CP} + 1.92\ \text{CF} - 12.55\ \text{Ash}$ ($r^2 = 0.76$).

Discussion

The chemical composition of the MBM samples used in this study are similar to those was reported by Young et al. (1977), Batterman et al. (1980), Sibbald, et al. (1980), Shi and Noblet (1993), Wang and Parsons (1998) and Ravindran et al. (2002) and relatively higher than what Sartorelli et al. (2003) reported. Sartorelli et al. (2003) reported relatively lower values for CP and GE but relatively higher values for percent ash, P and Ca. 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 of these MBM sample as revealed by Table 2 and their amino acids composition (Table 3) may be due to the effects of location, processing methods (Wang and Parsons 1998) and or the source of the MBM (Kirstein, 1999) on its quality 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 inclusion of MBM in the basal diet by replacing some amounts of corn and SBM resulted in an increase in the GE of the diet which invariably means an availability of more (gross) energy for digestion and absorption assuming similar digestibility/availability when compared with other MBM samples. However, the inclusion of MBM sample 1 resulted in a reduced GE at 5 and 10 % level relative to the basal diet. This could be due to the low GE value of this MBM sample (lowest of all the 12 MBM samples 3,493 kcal / kg).

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). The energy contents of feed ingredients and feces are measured in the form of GE. The GE of diets, however, does not tell us much about how available or useful to the animals such energy is. The DE, which is the energy in feed consumed minus the energy lost in feces, gives us a fair idea on the usability of the energy in the original feed. The ME on the other hand, is arrived at by deducting the energy lost in urine from the DE. 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 balance 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. 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 AME_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).

Level of MBM inclusion did not produce any significant effects on diet ME except for MBM sample 2 in which the ME of the diet was reduced significantly with increasing level of MBM in the diet. Our values are slightly higher than what Shi and Noblet (1993) reported in their study. This difference again might be due to the nature of feed used in their study (high fiber content). The quality of MBM as a result of sources and processing techniques could be a factor in the results obtained from this study.

Metabolizable energy value of meat and bone meal

The large variation in the AME and AME_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 1,585 and 3,345 kcal / kg. The AME_n had a range of between 1,529 and 3,395 kcal / kg. These values are close to what Batterman et al. (1980) and Shi and Noblet (1993) reported for growing pigs, 2,470 to 2,803 and 2,796 kcal / kg, respectively. From the data Wang and Parsons (1998) reported, it is expected that the AME and AME_n values of MBM sample 2 would give a higher AME and AME_n than that of 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 AME and AME_n of the diets. The contribution of MBM sample 2 to diet AME 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 AME_n values obtained.

Batterman 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.

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 AME_n. Having all of these nutrients in required ratio and quality is a key to optimizing the energy content of MBM in pig.

The results presented in this study show the variation that could be obtained in MBM quality. Also, it reveals that the GE or CP or CF of the MBM alone is not directly proportional to the AME or AME_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. Template for diet composition (g / kg)

Ingredients in g/kg	MBM$_{BD}$ [a]	MBM$_1$ [b]	MBM$_2$ [c]
Corn	715	733	750
Soybean Meal	235	180	125
Dical (20% Ca; 18.5% P)	16	8	0
Limestone (36% Ca)	9	4	0
Salt	3	3	3
Vitamin Premix [d]	3	3	3
Selenium Premix [e]	0.5	0.5	0.5
Trace Mineral Premix [f]	1.5	1.5	1.5
Lysine-HCl	1.5	1.5	1.5
Antioxidant	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 & Energy [h]			
Protein, g/kg	170.0	170.2	170.3
DE, kcal/kg	3,431.1	3,414.3	3,393.9
ME, kcal/kg	3,281.8	3,268.5	3,251.7
Ca, g/kg	7.3	8.7	10.6
P, g/kg	6.4	7.1	7.8
Digestible amino acids, g/kg			
Lys	8.62	7.19	5.76
Met	2.40	2.11	1.83
Met+Cys	4.75	4.20	3.63
Thr	5.36	4.58	3.80
Trp	1.83	1.53	1.24

[a] MBM$_{BD}$ = Diet containing 0 % meat and bone meal (or the basal diet).

[b] MBM$_1$ = Diet containing 5 % meat and bone meal.

[c] MBM$_2$ = Diet containing 10 % meat and bone meal.

[d] Contained per kg of diet: Vit. A, 2440 IU; Vit. D3, 243 IU; Vit E, 9.3 IU; Vit. K activity, 1.9 mg; Menadione, 600 ug; Vit B12, 12.4 mg; Riboflavin, 2.4 mg; d-pantothenic acid, 9 mg; Niacin, 14 mg.

[e] 600 ug Se per g of premix.

[f] Contained per kg diet: Fe, 179 mg; Mn, 60 mg; Zn, 150 mg; Cu, 17.5 mg; I, 3mg.

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

[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. General nutrient composition of meat and bone meal samples[1].

Meat & bone meal Sample ID	Dry Matter, %	Crude protein, %[2]	Crude Fat, %	Phosphorus, %	Calcium, %	Ash, %	Gross Energy, kcal/kg
A1-02 1	92.12	49.67	9.11	6.17	14.58	38.19	3,493
A1-02 2	96.37	51.24	9.77	4.65	10.64	31.74	3,881
A1-02 3	94.51	56.42	11.08	2.83	6.16	23.23	4,469
A1-02 4	93.99	53.80	14.08	2.56	5.43	20.03	4,661
A1-02 5	96.23	54.91	11.03	4.08	9.35	27.96	4,107
A1-02 6	98.21	61.91	9.69	2.67	6.16	20.27	4,732
A1-02 7	97.93	54.25	9.33	4.34	10.25	29.12	4,155
A1-02 8	99.07	53.75	11.55	3.94	8.80	26.14	4,342
A1-02 9	98.94	53.57	10.65	3.61	8.43	24.82	4,320
A1-02 10	97.19	52.54	12.05	3.68	8.51	25.03	4,377
A1-02 11	97.34	60.48	11.34	2.74	6.63	21.30	4,671
A1-02 12	96.92	53.72	15.12	3.76	8.72	26.12	4,490

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

[2] Crude protein, CP = Nitrogen*6.25).

Table 3. Amino acid composition of the 12 samples of meat and bone meal

	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

W/W%= grams per 100 grams of sample.
Results are expressed on an "air dry" basis.

Table 4. Gross energy values and percent fat of the experimental diets

	Gross energy, kcal/kg [a]		
Sample ID	0 % MBM	5 % MBM	10 % MBM
A1-02 1	4,290	4,278	4,283
A1-02 2	4,259	4,284	4,305
A1-02 3	4,258	4,294	4,361
A1-02 4	4,266	4,327	4,366
A1-02 5	4,374	4,389	4,397
A1-02 6	4,347	4,405	4,433
A1-02 7	4,345	4,333	4,337
A1-02 8	4,288	4,309	4,326
A1-02 9	4,282	4,293	4,308
A1-02 10	4,246	4,279	4,298
A1-02 11	4,264	4,343	4,320
A1-02 12	4,254	4,284	4,305
	Diet fat content, %		
A1-02 1	4.13	4.56	4.78
A1-02 2	3.79	4.25	4.97
A1-02 3	4.23	4.58	5.52
A1-02 4	3.97	5.06	6.31
A1-02 5	4.02	4.41	4.83
A1-02 6	3.77	4.49	4.72
A1-02 7	3.56	4.32	5.19
A1-02 8	3.78	4.08	4.55
A1-02 9	2.88	4.30	4.49
A1-02 10	2.53	342	3.95
A1-02 11	2.84	3.53	3.98
A1-02 12	3.09	3.71	4.44

[a] Values are means of three replicates per sample on DM basis.
MBM = Meat and bone meal.

Table 5. Digestible energy of diets (on DM basis) in growing pigs fed diets containing 0, 5, or 10 % meat and bone meal from different sources.

	Digestible energy, kcal/kg [a]			
Sample ID	0 % MBM	5 % MBM	10 % MBM	SD
A1-02 1	3,547	3,603	3,536	134
A1-02 2[b]	3,595	3,544	3,466	72
A1-02 3	3,614	3,606	3,661	67
A1-02 4	3,615	3,627	3,666	69
A1-02 5[c]	3,683	3,745	3,650	54
A1-02 6	3,759	3,773	3,735	46
A1-02 7	3,601	3,574	3,529	98
A1-02 8	3,671	3,687	3,717	107
A1-02 9	3,593	3,604	3,593	66
A1-02 10	3,543	3,616	3,611	129
A1-02 11	3,573	3,596	3,596	58
A1-02 12	3,359	3,615	3,567	84

[a] Values are least square means of 8 pigs per treatment; MBM = Meat and bone meal.

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

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

Table 6. Energy digestibility of diets in growing pigs fed diets containing 0, 5, or 10 % meat and bone meal from different sources.

	Energy digestibility, % [a]			
Sample ID	0 % MBM	5 % MBM	10 % MBM	SD
A1-02 1	82.85	84.31	82.61	3.066
A1-02 2[b]	84.41	82.71	80.50	2.037
A1-02 3	84.91	84.13	84.09	1.537
A1-02 4	84.83	83.88	84.03	1.607
A1-02 5[cd]	84.28	84.34	83.10	1.244
A1-02 6[b]	86.49	85.67	84.25	1.052
A1-02 7	82.95	83.12	82.46	2.135
A1-02 8	85.66	85.62	85.95	2.478
A1-02 9	83.90	84.00	83.44	1.583
A1-02 10	83.43	84.48	84.01	2.975
A1-02 11	83.78	82.82	83.23	1.341
A1-02 12	84.34	84.40	82.88	1.968

[a] Values are least square means of 8 pigs per treatment; MBM = Meat and bone meal.

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

[c] Linear effect of meat and bone meal $P < 0.1$.

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

Table 7. Metabolizable energy of diets (DM basis) in growing pigs fed diets containing 0, 5, or 10 % meat and bone meal from different sources.

	Metabolizable energy, kcal/kg [a]			
Sample ID	0 % MBM	5 % MBM	10 % MBM	SD
A1-02 1	3,438	3,505	3,446	134
A1-02 2[b]	3,483	3,440	3,365	70
A1-02 3	3,508	3,510	3,559	66
A1-02 4	3,516	3,516	3,564	71
A1-02 5[c]	3,553	3,622	3,530	47
A1-02 6[d]	3,647	3,674	3,625	42
A1-02 7	3,495	3,458	3,421	102
A1-02 8	3,538	3,570	3,603	100
A1-02 9	3,451	3,525	3,455	115
A1-02 10	3,423	3,500	3,495	136
A1-02 11	3,478	3,494	3,487	56
A1-02 12	3,480	3,492	3,465	102

[a] Values are least square means of 8 pigs per treatment; MBM = Meat and bone meal.
[b] Linear effect of meat and bone meal $P < 0.05$.
[c] Quadratic effect of meat and bone meal $P < 0.05$.
[d] Quadratic effect of meat and bone meal $P < 0.1$.

Table 8. Metabolizable energy corrected for nitrogen of diets (DM basis) in growing pigs fed diets containing 0, 5, or 10 % meat and bone meal from different sources.

	Metabolizable energy corrected for nitrogen, kcal/kg [a]			
Sample ID	0 % MBM	5 % MBM	10 % MBM	SD
A1-02 1	3,268	3,342	3,284	129
A1-02 2[b]	3,330	3,281	3,203	71
A1-02 3	3,343	3,350	3,379	57
A1-02 4[c]	3,330	3,369	3,414	63
A1-02 5[d]	3,339	3,440	3,356	49
A1-02 6[e]	3,345	3,500	3,440	41
A1-02 7	3,338	3,280	3,261	96
A1-02 8	3,378	3,414	3,437	97
A1-02 9	3,273	3,347	3,290	103
A1-02 10	3,235	3,327	3,327	127
A1-02 11	3,298	3,310	3,330	53
A1-02 12	3,465	3,486	3,470	94

[a] Values are least square means of 8 pigs per treatment; MBM = Meat and bone meal.
[b] Linear effect of meat and bone meal $P < 0.05$.
[c] Linear effect of meat and bone meal $P < 0.1$.
[d] Quadratic effect of meat and bone meal $P < 0.05$.
[e] Quadratic effect of meat and bone meal $P < 0.1$.

Table 9. Five-day meat and bone meal intake by growing pigs fed diets containing 0, 5, or 10 % meat and bone meal from different sources.

	Meat and bone meal intake, g [a]			
Sample ID	0 % MBM	5 % MBM	10 % MBM	SD
A1-02 1[b]	0.00	0.374	0.713	0.0450
A1-02 2[b]	0.00	0.378	0.708	0.0430
A1-02 3[b]	0.00	0.344	0.629	0.0413
A1-02 4[b]	0.00	0.369	0.760	0.0391
A1-02 5[b]	0.00	0.350	0.666	0.0498
A1-02 6[bc]	0.00	0.381	0.676	0.0441
A1-02 7[b]	0.00	0.354	0.616	0.0676
A1-02 8[b]	0.00	0.284	0.556	0.0628
A1-02 9[bd]	0.00	0.333	0.599	0.0365
A1-02 10[b]	0.00	0.296	0.599	0.0430
A1-02 11[b]	0.00	0.351	0.688	0.0320
A1-02 12[b]	0.00	0.323	0.634	0.0310

[a] Values are least square means of 8 pigs per treatment; MBM = Meat and bone meal.
[b] Linear effect of meat and bone meal $P < 0.05$.
[c] Quadratic effect of meat and bone meal $P < 0.05$.
[d] Quadratic effect of meat and bone meal $P < 0.1$.

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

	Meat and bone meal contribution to ME, kcal/kg [a]			
Sample ID	0 % MBM	5 % MBM	10 % MBM	SD
A1-02 1[bc]	0.00	1,481	1,988	320.4
A1-02 2[bd]	0.00	816	1,095	322.7
A1-02 3[b]	0.00	968	2,029	295.7
A1-02 4[b]	0.00	1,000	2,428	387.1
A1-02 5[b]	0.00	1,426	1,698	355.4
A1-02 6[bc]	0.00	1,260	1,786	325.7
A1-02 7[b]	0.00	968	1,277	509.1
A1-02 8[b]	0.00	824	1,856	251.3
A1-02 9[bc]	0.00	1,356	1,631	544.7
A1-02 10[b]	0.00	1,235	2,016	355.7
A1-02 11[b]	0.00	1,063	1,909	305.9
A1-02 12[b]	0.00	922	1,638	518.2

	Meat and bone meal contribution to ME_n, kcal/kg [a]			SD
A1-02 1[bc]	0.00	1,486	1,946	289.7
A1-02 2[b]	0.00	708	1,024	301.3
A1-02 3[b]	0.00	924	1,854	276.6
A1-02 4[b]	0.00	1,227	2,588	344.9
A1-02 5[b]	0.00	1,246	1,521	338.5
A1-02 6[bc]	0.00	1,356	1,745	295.9
A1-02 7[b]	0.00	764	1,182	492.9
A1-02 8[b]	0.00	828	1,763	292.6
A1-02 9[bc]	0.00	1,305	1,627	477.8
A1-02 10[b]	0.00	1,275	2,046	352.5
A1-02 11[b]	0.00	984	1,965	290.6
A1-02 12[bd]	0.00	1,176	1,748	316.8

[a] Values are least square means of 8 pigs per treatment; MBM = Meat and bone meal. ME= Metabolizable energy; ME_n = Metabolizable energy corrected for nitrogen.

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

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

[d] Quadratic effect of meat and bone meal $P < 0.1$.

Table 11. Apparent metabolizable energy of twelve samples of meat and bone meal (on DM basis) in growing pigs fed diets containing 0, 5, or 10 % meat and bone meal from different sources.

MBM sample ID	AME[a]	AME_n[b]
A1-02 1	2,860	2,785
A1-02 2	1,585	1,529
A1-02 3	3,199	2,909
A1-02 4	3,138	3,329
A1-02 5	2,594	2,327
A1-02 6	2,690	2,645
A1-02 7	2,280	2,093
A1-02 8	3,105	2,975
A1-02 9	2,762	2,742
A1-02 10	3,345	3,395
A1-02 11	2,782	2,844
A1-02 12	2,582	2,752
Mean	2,744	2,694

[a] AME= Apparent metabolizable energy.

[b] AME_n = Apparent metabolizable energy corrected for nitrogen.

Table 12. Pearson correlation coefficients between apparent metabolizable energy and apparent metabolizable energy corrected for nitrogen of twelve meat and bone meal samples and the major chemical constituents of meat and bone meal samples [1].

Apparent metabolizable energy of twelve meat and bone meal samples for pigs

	AME	GE	CP	CF	Ash	Ca	P
AME	1.000						
GE	0.39 (0.210)	1.000					
CP	0.13 (0.689)	0.75 (0.005)	1.000				
CF	0.36 (0.248)	0.53 (0.078)	-0.03 (0.925)	1.000			
Ash	-0.41 (0.189)	-0.98 (<.0001)	-0.74 (0.006)	-0.46 (0.129)	1.000		
Ca	-0.37 (0.235)	-0.95 (<.0001)	-0.71 (0.010)	-0.46 (0.128)	0.98 (<.0001)	1.000	
P	-0.36 (0.248)	-0.96 (<.0001)	-0.75 (0.005)	-0.44 (0.147)	0.99 (<.0001)	0.996 (<.0001)	1.000

Apparent metabolizable energy corrected for nitrogen for twelve meat and bone meal samples for pigs

	AME_n	GE	CP	CF	Ash	Ca	P
AME_n	1.000						
GE	0.47 (0.124)	1.000					
CP	0.11 (0.732)	0.75 (0.005)	1.000				
CF	0.53 (0.080)	0.53 (0.078)	-0.03 (0.925)	1.000			
Ash	-0.47 (0.127)	-0.98 (<.0001)	-0.74 (0.006)	-0.46 (0.129)	1.000		
Ca	-0.41 (0.185)	-0.95 (<.0001)	-0.71 (0.010)	-0.46 (0.128)	0.98 (<.0001)	1.000	
P	-0.41 (0.189)	-0.96 (<.0001)	-0.75 (0.005)	-0.44 (0.147)	0.99 (<.0001)	0.996 (<.0001)	1.000

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[1] AME = Apparent metabolizable energy (kcal / kg); AME_n = Apparent metabolizable energy corrected for nitrogen (kcal / kg); GE = Gross energy (kcal / kg); CP = Crude protein (g / kg); CF = Crude fat (g / kg); Ash (g/kg); Ca = Calcium (g / kg); P = Phosphorus, (g / kg); MBM = Meat and bone meal. Value in parenthesis is the P value.

Overall Regression Equations:

AME = 7872 - 0.39 GE - 3.39 CP + 3.39 CF – 7.52 Ash (r^2 = 0.23).
AME = -1074 + 1.29 GE – 4.16 CP - 1.16 CF - 25.16 Ca + 76.16 P (r^2 = 0.22).
AME = 6894 + 0.04 GE - 5.11 CP - 5.96 Ash (r^2 = 0.23); AME = 6345 - 4.30 CP + 1.85 CF - 5.57 Ash (r^2 = 0.23).
AME_n = 5108 + 0.20 GE - 5.01 CP + 6.18 CF – 4.74 Ash (r^2 = 0.37).
AME_n = -1513 + 1.64 GE – 7.06 CP + 2.27 CF + 7.17 Ca + 1.7 P (r^2 = 0.37).
AME_n = 3325 + 1.00 GE - 8.15 CP - 1.88 Ash (r^2 = 0.36); AME_n = 5896 - 4.54 CP + 6.97 CF - 5.74 Ash (r^2 = 0.37).

Table 13. Pearson correlation coefficients between apparent metabolizable energy and apparent metabolizable energy corrected for nitrogen of ten meat and bone meal samples and the major chemical constituents of meat and bone meal samples [1].

	Apparent metabolizable energy of ten meat and bone meal samples for pigs						
	AME	GE	CP	CF	Ash	Ca	P
AME	1.000						
GE	0.31 (0.384)	1.000					
CP	-0.202 (0.576)	0.61 (0.060)	1.000				
CF	0.30 (0.395)	0.29 (0.409)	-0.40 (0.246)	1.000			
Ash	-0.44 (0.208)	-0.93 (<.0001)	-0.59 (0.075)	-0.17 (0.646)	1.000		
Ca	-0.49 (0.150)	-0.87 (0.001)	-0.53 (0.112)	-0.20 (0.589)	0.96 (<.0001)	1.000	
P	-0.42 (0.229)	-0.90 (0.0004)	-0.61 (0.061)	-0.15 (0.679)	0.97 (<.0001)	0.99 (<.0001)	1.000
	Apparent metabolizable energy corrected for nitrogen for ten meat and bone meal samples for pigs						
	AME_n	GE	CP	CF	Ash	Ca	P
AME_n	1.000						
GE	0.51 (0.129)	1.000					
CP	-0.20 (0.579)	0.61 (0.060)	1.000				
CF	0.55 (0.098)	0.29 (0.409)	-0.40 (0.246)	1.000			
Ash	-0.57 (0.088)	-0.93 (<.0001)	-0.59 (0.075)	-0.17 (0.646)	1.000		
Ca	-0.55 (0.102)	-0.87 (0.001)	-0.53 (0.112)	-0.20 (0.589)	0.96 (<.0001)	1.000	
P	-0.50 (0.141)	-0.90 (0.0004)	-0.61 (0.061)	-0.15 (0.679)	0.97 (<.0001)	0.99 (<.0001)	1.000

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[1] AME = Apparent metabolizable energy (kcal / kg); AME_n = Apparent metabolizable energy corrected for nitrogen (kcal / kg); GE = Gross energy (kcal / kg); CP = Crude protein (g / kg); CF = Crude fat (g / kg); Ash (g/kg); Ca = Calcium (g / kg); P = Phosphorus, (g / kg); MBM = Meat and bone meal. Value in parenthesis is the P value.

[2] Overall Regression Equation:

AME = 12050 - 0.33 GE - 8.23 CP - 2.49 CF – 11.85 Ash (r^2 = 0.54).
AME = 6139 + 0.64 GE – 8.32 CP - 6.01 CF - 42.91 Ca + 74.79 P (r^2 = 0.59).
AME = 12744 – 0.65 GE - 6.93 CP - 12.91 Ash (r^2 = 0.53); AME = 10805 – 9.00 CP – 3.75 CF – 10.34 Ash (r^2 = 0.53).
AME_n = 8182 + 0.70 GE - 11.01 CP - 0.75 CF – 9.33 Ash (r^2 = 0.77).
AME_n = 3796 + 1.58 GE – 12.32 CP - 3.67 CF - 9.39 Ca + 0.83 P (r^2 = 0.74).
AME_n = 8391 + 0.60 GE - 10.61 CP - 9.66 Ash (r^2 = 0.76); AME_n = 10838 – 9.36 CP + 1.92 CF - 12.55 Ash (r^2 = 0.76).