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Metabolizable energy value of meat and bone meal for pigs¹

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ABSTRACT: Metabolizable energy and N-corrected ME (ME_n) values of 12 samples of meat and bone meal (MBM) were determined using 288 barrows with an average BW of 35 ± 3.1 kg. For each of 12 MBM samples, diets were formulated by substituting 0, 50, or 100 g/kg MBM (as-fed basis) in a basal 170 g of 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 eight barrows in individual metabolism crates in metabolism studies that used a 5-d acclimation, which was followed by a 5-d period of total, but separate, collection of feces and urine. The GE, CP, crude fat (CF), ash, Ca, and P contents of the MBM samples, per kilogram (DM 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, and 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 samples was calculated from the slope of the regression of MBM contribution (in kilocalories) to ME and ME_n intake, respectively, against quantity (in kilograms) of MBM

intake. The ME and ME_n of the 12 MBM samples ranged from 1,569 to 3,308 kcal/kg DM and 1,474 to 3,361 kcal/kg DM, respectively. The variation in ME was described by the regression equation: $ME = 6,982 + 0.283 \text{ GE (kcal/kg)} - 6.26 \text{ CP (g/kg)} - 3.75 \text{ CF (g/kg)} + 129.47 \text{ P (g/kg)} - 54.91 \text{ Ca (g/kg)} - 6.57 \text{ ash (g/kg)}$, with an R^2 of 0.612 and SD of 376. For ME_n , the corresponding equation was: $ME_n = 3,937 + 1.089 \text{ GE (kcal/kg)} - 8.74 \text{ CP (g/kg)} + 3.58 \text{ CF (g/kg)} + 60.89 \text{ P (g/kg)} - 15.92 \text{ Ca (g/kg)} - 9.57 \text{ ash (g/kg)}$, with an R^2 of 0.811 and SD of 314. Simpler regression equations describing variation in ME or ME_n were $9,254 - 7.41 \text{ CP (g/kg)} - 9.41 \text{ ash (g/kg)}$, with R^2 of 0.504 and SD of 278; or $12,504 - 10.71 \text{ CP (g/kg)} - 13.44 \text{ ash (g/kg)}$, with R^2 of 0.723 and SD of 249. Pearson correlation analysis indicated that the variations in ME and ME_n of the MBM samples were not related to any of the major chemical components. The results indicated 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 use in MBM for pigs.

Key Words: Meat and Bone Meal, Metabolizable Energy, Pig, Regression, Slope

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Introduction

Meat and bone meal (MBM) is rendered animal offal, including restaurant grease, plate waste, trimmings and bones, viscera and digesta, blood, heads, hooves, hides, and dead livestock that are considered unfit for human consumption (Shirley and Parsons, 2001). The rendering of a wide variety of raw materials can result

in differences in nutrient and energy content of MBM. This variation in content necessitates information on use of these ingredient components by the animal. Information on ME and N-corrected ME (ME_n) can assist in 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 of DM in growing pigs; however, ME content of these samples was not determined. In another study, Shi and Noblet (1993) reported ME of 2,175 and 3,011 kcal/kg of DM for growing pigs and sows. These 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 diets. Thus, the objective of this study was to determine the ME and ME_n in 12 samples of

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Table 1. Nutrient and energy composition of meat and bone meal (MBM) samples on a DM basis^{a,b}

MBM Sample No.	DM, g/kg	CP, g/kg ^c	Crude fat, g/kg	P, g/kg	Ca, g/kg	Ash, g/kg	GE, kcal/kg
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

^aPresented in Adedokun and Adeola (2005).

^bValues are means of triplicates analyses.

^cCP = N × 6.25.

MBM for pigs, and to develop regression equations that described the variation in ME or ME_n of MBM in relation to chemical composition.

Materials and Methods

Meat and Bone Meal Samples

Twelve samples of MBM were selected to provide a wide range of chemical composition (Table 1) and were used in these experiments to determine the ME and ME_n for pigs. All samples were cooked in a Dupps Continuous Cooker at 129 to 135°C except Sample 11, which was cooked at 132 to 138°C. Sample 1 was derived from all-beef packer slaughter material. Sample 2 was derived from a high percentage of beef packer slaughter material, with a small component of extra offal and swine raw material. Sample 3 was derived from 30% bovine whole carcasses and 65% swine whole carcasses, with a small component of meat processing trimmings of multiple species. 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. 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 a small quantity of poultry processing and whole bird carcasses. 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. Sample 8 was packer-derived material from exclusive swine slaughter. Sample 9 was derived from 80% beef slaughter and processing, 10% whole beef and swine carcasses of near equal weight proportions, and small amount of poultry

heads, necks, and discards. Sample 10 was derived from raw material composed of 60% beef packer material, 25% poultry backs and necks, and 15% grocery store trimmings, and outdated muscle meats and processed meats. 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 greater bone content. There was no whole carcass material from either beef or swine. Sample 12 was derived from nearly exclusive all pork from a packer processing sows for sausage.

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, 50, or 100 g of MBM substitution of corn and soybean meal (SBM) in a basal 170 g CP/kg (as-fed basis) corn-SBM diet. Corn and SBM were adjusted to constant ratio (1.8:5.5 for the 50 g MBM/kg diet, and 3.6:11 for the 100 g MBM/kg diet) in the substitutions. Because all the energy in the basal diet was derived from corn and SBM, this constant ratio was key for the algebraic equations (described below) used in the indirect method of ME determination to derive the contribution of MBM to energy intake. To minimize the negative effect of the use of N-containing compounds for energy, the three diets for each MBM sample were formulated to have comparable CP content (Table 2). The same batches of corn and SBM were used for formulating all diets, so the only source of variation was the 12 samples of MBM.

Pig Metabolizable Energy Assay

The Purdue University Animal Care and Use Committee approved all animal care procedures. Two hundred and eighty-eight Yorkshire-Landrace barrows,

Table 2. Composition of diets, as-fed basis^a

	Diets		
	1	2	3
Meat and bone meal, g/kg:	0	50	100
Ingredients, g/kg			
Corn	715	733	750
Soybean meal ^b	235	180	125
Dicalcium phosphate ^c	16	8	0
Limestone ^d	9	4	0
Salt	3	3	3
Vitamin premix ^e	3	3	3
Selenium premix ^f	0.5	0.5	0.5
Trace mineral premix ^g	1.5	1.5	1.5
L-Lysine-HCl	1.5	1.5	1.5
Antioxidant ^h	0.5	0.5	0.5
Meat and bone meal	0	50	100
Chromic oxide premix ⁱ	15	15	15
Calculated nutrients and energy ^j			
CP, 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

^aPresented in Adedokun and Adeola (2005).

^bContained 480 g of CP/kg diet.

^cContained 200 g of Ca and 185 g of P/kg.

^dContained 360 g of Ca/kg.

^eProvided per kilogram of diet: vitamin A (retinyl acetate), 7,320 IU; vitamin D₃ (cholecalciferol), 729 IU; vitamin E (DL- α -tocopheryl acetate), 27.9 IU; vitamin K activity, 5.7 mg; menadione, 1,800 μ g; vitamin B₁₂, 37.2 mg; riboflavin, 7.2 mg; D-pantothenic acid, 27 mg; and niacin, 42 mg.

^fProvided 300 μ g of Se (as sodium selenite)/kg of diet.

^gProvided per kilogram of diet: Fe (as FeSO₄·H₂O), 268.5 mg; Mn, (as MnSO₄) 90 mg; Zn (as ZnSO₄), 225 mg; Cu (as CuSO₄), 26.3 mg; and I [as Ca(IO₃)₂], 4.5 mg.

^hProvided 330 mg of ethoxyquin/kg of diet.

ⁱChromic oxide (Cr₂O₃) premix added as index at a ratio 1:4 of chromic oxide:finely ground corn supplying 3 g of chromic oxide/kg diet.

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

with an average BW of 35 \pm 3.1 kg, were used in this study. The basal diet was corn-SBM based with 0 g MBM per kilogram diet (Diet 1; Table 2). For each MBM source, each of the three diets containing 0, 50, or 100 g of MBM/kg diet (Diets 1, 2, or 3; Table 2) was fed to eight barrows in a metabolism assay that used a 5-d adjustment period, followed by a 5-d period of total, but separate, collection of feces and urine. Pigs were housed in stainless-steel metabolism crates (1.85 m \times 0.70 m), equipped with stainless steel feeders and low pressure water nipples 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 BW at the beginning of the collection. They were fed equal quantities of diets twice daily (0700 and 1700). This quantity was adjusted until each pig was able to consume all the feed that was given. 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. For 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, with the remaining feed provided as described for the study initiation. On 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 Analyses

All MBM samples were analyzed for CP (N \times 6.25), AA, crude fat (CF), Ca, and P at the University of Missouri Experiment Station Chemical Laboratory. Nitrogen content of the MBM samples was determined by the combustion method (990.03; AOAC, 2000). Amino acids were determined by HPLC (982.30 E [a, b, c]; AOAC, 2000). Crude fat was determined by the ether extraction method (934.01; AOAC, 2000). Meat and bone meal samples were digested by the nitric and perchloric acid wet digestion method (935.13A; AOAC, 2000). Calcium and P were determined by inductively coupled plasma atomic emission spectroscopy (990.08; AOAC, 2000).

The frozen feces were thawed (the entire collection for each pig was pooled), placed in an aluminum pan, weighed, and dried at 55°C. The dried feces, MBM samples, and diets were ground to pass a 0.5-mm screen to facilitate analysis, after which these samples were thoroughly mixed and sampled. Dry matter content of the feces, MBM samples, and diets was determined by drying the samples at 100°C for 24 h. The GE content of feces, MBM samples, and diets was determined by adiabatic bomb calorimetry (Model 1261; Parr Instrument Co., Moline, IL), with benzoic acid as a standard. Nitrogen content of feces and diets was determined by the combustion method (990.03; AOAC, 2000) using a Leco Model FP-2000 N analyzer (Leco Corp., St. Joseph, MI), with EDTA as a standard. The ash content of the MBM samples was determined by drying the sample overnight at 100°C, followed by ashing in a muffle furnace for 18 h at 600°C.

The urine collected was thawed, thoroughly mixed and sampled, and filtered through 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 (Nasco, Fort Atkinson, WI) bags at -18°C. The dried urine sam-

ples were then analyzed for GE and N as described for fecal samples. Duplicate analyses were performed on all diets, feces, MBM samples, orts, and urine samples.

Calculations

The ME content of the diet was calculated as the difference between energy in the dietary 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 and 0.235 soybean meal (SBM). Thus:

$$\text{ME}_1 = 0.715 \text{ corn} + 0.235 \text{ SBM.} \quad [\text{Eq. 1}]$$

Using the ME contents of corn and SBM at 3,420 and 3,385 kcal/kg (NRC, 1998), respectively, and their ratios:

$$\begin{aligned} \text{ME}_1 &= (0.715 \times 3,420/3,385 \text{ SBM}) \\ &+ 0.235 \text{ SBM; SBM} = \text{ME}_1/0.9574; \\ \text{ME}_1 &= 0.715 \text{ corn} + (0.235 \times 3,385 \text{ corn}/3,420); \\ \text{corn} &= \text{ME}_1/0.9476. \end{aligned}$$

The ME in Diet 2 (the diet containing 50 g MBM/kg diet, ME₂) was contributed by 0.733 corn, 0.180 SBM, and 0.05 MBM. Thus:

$$\begin{aligned} \text{ME}_2 &= 0.733 \text{ corn} + 0.180 \text{ SBM} \quad [\text{Eq. 2}] \\ &+ 0.05 \text{ MBM}_2. \end{aligned}$$

The ME in Diet 3 (the diet containing 100 g of MBM/kg diet, ME₃) was contributed by 0.750 corn, 0.125 SBM, and 0.10 MBM. Thus:

$$\begin{aligned} \text{ME}_3 &= 0.750 \text{ corn} + 0.125 \text{ SBM} \quad [\text{Eq. 3}] \\ &+ 0.1 \text{ MBM}_3. \end{aligned}$$

Using the ME contents of corn and SBM at 3,420 and 3,385 kcal/kg (NRC, 1998), respectively, and their ratios, and substituting corn and SBM in the equations above gives:

$$\begin{aligned} \text{ME}_2 &= [0.733(\text{ME}_1/0.9476)] + [0.180 \times (\text{ME}_1/0.9574)] \\ &+ 0.05 \text{ MBM}_2; \\ \text{ME}_3 &= [0.750 (\text{ME}_1/0.9476)] + [0.125 \times (\text{ME}_1/0.9574)] \\ &+ 0.1 \text{ MBM}_3. \end{aligned}$$

Rearranging the above gives:

$$\text{MBM}_2 = (\text{ME}_2 - 0.96154 \text{ ME}_1)/0.05; \quad [\text{Eq. 4}]$$

for the contribution (kcal/kg) of MBM to ME of Diet 2

$$\text{MBM}_3 = (\text{ME}_3 - 0.92203 \text{ ME}_1)/0.1; \quad [\text{Eq. 5}]$$

for the contribution (kcal/kg) of MBM to ME of Diet 3.

The products of Eq. 4 or 5 and the quantities (in kilograms) of MBM intake by 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 Eq. 1 to 5. The ME corrected for retained N (ME_n) was calculated using a caloric value of 7.45 kcal/g of N (Harris et al., 1972).

Statistical Analyses

The data for each MBM sample were analyzed as a randomized complete block design of three diets in eight blocks, using the GLM procedure 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 GLM procedure of SAS, with block as a source of variation and the solutions option. The slope of the regression gave the ME or ME_n content of the MBM sample. Pearson correlations were generated using the CORR procedure 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 12 MBM samples showing the variations in CP, CF, Ca, P, ash, and GE are given in Table 1. The AA composition of the 12 samples of MBM is presented in Table 3. The analyzed results presented in Tables 2 and 3 indicated that MBM Samples 6 and 11 were high in CP and AA, but those of Samples 1 and 2 were relatively low. There was an increase in GE and fat contents of diets with an increase in MBM substitution (data not shown). Similarly, the ME and ME_n values of diets increased as MBM substitution increased from 0 to 100 g/kg, except for MBM Sample 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 increases in MBM in the diet for the 12 MBM samples (Table 4). Quadratic and linear effects ($P < 0.05$) were observed for pigs on Sample 6. The contribution of MBM to ME and ME_n intakes in pigs that received diets with MBM added at 0, 50, or 100 g/kg diet are presented in Tables 5 and 6, respectively. The inclusion of MBM resulted in linear increases ($P < 0.05$) in contribution of MBM to ME and ME_n intake. Quadratic responses ($P < 0.05$), as well as linear responses, in MBM contribution to ME and ME_n intake were observed for MBM Samples 1, 6, and 9. The ME and ME_n for each of the MBM samples are presented in Table 7. Metabolizable energy values ranged from 1,569 to 3,308 kcal/kg of DM; ME_n values were between 1,474 and 3,361 kcal/kg of DM.

Table 3. Amino acid composition (g/kg) of the 12 samples of meat and bone meal (MBM), as-fed basis

	MBM Sample No.											
	1	2	3	4	5	6	7	8	9	10	11	12
Essential AA												
Arginine	32.1	33.3	33.9	33.2	35.4	40.5	36.5	36.9	36.1	33.5	37.8	35.5
Histidine	7.6	9.1	12.9	11.7	12.1	13.2	9.9	10.5	9.6	10.5	14.5	10.8
Isoleucine	11.2	13.9	17.9	16.8	17.2	21.5	16.0	16.0	15.7	15.4	19.4	16.9
Leucine	25.6	28.1	34.3	33.8	33.6	41.7	32.0	33.0	31.9	31.5	40.6	33.1
Lysine	23.2	23.1	31.7	28.3	30.8	31.5	28.4	28.2	27.3	26.4	32.9	29.1
Methionine	5.5	5.0	6.6	6.9	7.9	8.4	8.1	8.2	7.2	6.6	8.2	8.3
Phenylalanine	13.8	15.2	18.1	17.4	17.8	22.5	17.0	17.5	17.0	17.2	21.6	17.8
Threonine	13.7	13.9	17.2	17.3	16.8	21.8	16.9	17.5	16.2	16.4	20.2	17.6
Tryptophan	3.3	3.2	4.2	4.1	4.3	4.7	3.9	3.8	3.7	3.6	4.7	4.0
Valine	17.6	21.0	24.9	23.3	23.6	30.7	22.5	23.5	22.8	22.3	28.4	23.0
Nonessential AA												
Alanine	34.5	35.7	35.9	32.6	34.5	38.2	36.7	35.6	36.1	33.8	40.7	35.3
Aspartic acid	31.5	33.7	39.8	38.5	39.1	45.6	38.3	39.5	37.6	37.2	44.7	39.6
Cysteine	3.1	2.7	4.3	4.7	4.9	8.6	4.9	5.8	4.1	4.7	5.5	4.5
Glutamic acid	54.9	59.0	73.3	66.0	65.3	78.0	66.8	69.6	65.2	64.7	74.2	65.1
Glycine	71.0	68.3	59.2	54.0	60.2	64.0	70.6	67.6	70.2	62.7	66.0	61.8
Hydroxylysine	3.9	2.9	2.3	2.3	2.4	2.4	3.1	2.8	3.0	2.4	2.4	2.9
Hydroxyproline	33.1	26.7	21.9	19.6	21.1	21.6	30.1	26.1	29.1	24.9	24.1	24.8
Lanthionine	0.3	0.8	0.5	0.4	0.6	1.4	0.5	1.3	0.4	0.5	0.9	0.6
Ornithine	0.4	0.6	1.0	0.7	0.2	1.1	0.2	0.7	0.7	0.6	1.1	0.7
Proline	42.4	40.6	37.8	34.0	36.3	44.7	42.4	41.6	42.4	39.6	42.8	38.4
Serine	16.8	14.4	17.5	17.8	15.9	26.9	19.3	19.9	18.1	19.1	22.1	17.7
Taurine	0.3	0.5	0.7	0.7	1.0	0.9	1.7	0.7	0.8	0.9	1.9	1.4
Tyrosine	8.8	9.7	12.9	12.2	11.9	15.4	11.6	12.7	11.5	11.7	14.2	12.1
Total	454.6	461.4	508.8	476.7	492.9	585.3	517.4	519.0	506.8	486.2	568.9	501.0

Because the ME value of Sample 1 was extremely high, and the ME of Sample 2 was low, they were deleted from the correlation and multiple linear regression analyses. This resulted in an approximately 80% decrease in variation and an approximately 40% improvement in the coefficient of determination. Pearson

Table 4. Five-day meat and bone meal (MBM) intake by growing pigs fed diets containing 0, 50, or 100 g of MBM from different sources per kilogram of diet

MBM Sample No.	MBM intake, kg ^a		SD
	50 g/kg MBM	100 g/kg MBM	
1 ^b	0.374	0.713	0.0450
2 ^b	0.378	0.708	0.0430
3 ^b	0.344	0.629	0.0413
4 ^b	0.369	0.760	0.0391
5 ^b	0.350	0.666	0.0498
6 ^{bc}	0.381	0.676	0.0441
7 ^b	0.354	0.616	0.0676
8 ^b	0.284	0.556	0.0628
9 ^b	0.333	0.599	0.0365
10 ^b	0.296	0.599	0.0430
11 ^b	0.351	0.688	0.0320
12 ^b	0.323	0.634	0.0310

^aValues are least squares means of eight pigs per treatment. Pigs on 0 g MBM/kg diet had zero MBM intake, and three levels of MBM inclusion (0, 50, and 100 g/kg) were used in the analysis.

^bLinear effect of meat and bone meal, $P < 0.05$.

^cQuadratic effect of meat and bone meal, $P < 0.05$.

correlation coefficients and multiple regression equations (presented in Tables 8 and 9, respectively) were therefore generated from Samples 3 to 12. Correlation coefficients relating ME and ME_n to GE, CP, CF, P, Ca,

Table 5. Five-day meat and bone meal contribution to ME intake of diets in growing pigs fed diets containing 0, 50, or 100 g of meat and bone meal (MBM) from different sources per kilogram of diet

MBM Sample No.	MBM contribution to ME intake, kcal ^a		
	50 g/kg MBM	100 g/kg MBM	SD
1 ^{bc}	1,481	1,988	320.4
2 ^b	816	1,095	322.7
3 ^b	968	2,029	295.7
4 ^b	1,000	2,428	387.1
5 ^b	1,426	1,698	355.4
6 ^{bc}	1,260	1,786	325.7
7 ^b	968	1,277	509.1
8 ^b	824	1,856	251.3
9 ^{bc}	1,356	1,631	544.7
10 ^b	1,235	2,016	355.7
11 ^b	1,063	1,909	305.9
12 ^b	1,166	1,638	341.8

^aValues are least squares means of eight pigs per treatment. Pigs on 0 g MBM/kg diet had zero MBM contribution to ME intake, and three levels of MBM inclusion (0, 50, and 100 g/kg) were used in the analysis.

^bLinear effect of meat and bone meal, $P < 0.05$.

^cQuadratic effect of meat and bone meal, $P < 0.05$.

Table 6. Five-day meat and bone meal (MBM) contribution to N-corrected ME (ME_n) of diets in growing pigs fed diets containing 0, 50, or 100 g of MBM from different sources per kilogram of diet

MBM Sample No.	MBM contribution to ME_n intake, kcal ^a		SD
	50 g/kg MBM	100 g/kg MBM	
1 ^{bc}	1,486	1,946	289.7
2 ^b	708	1,024	301.3
3 ^b	924	1,854	276.6
4 ^b	1,227	2,588	344.9
5 ^b	1,246	1,521	338.5
6 ^{bc}	1,356	1,745	295.9
7 ^b	764	1,182	492.9
8 ^b	828	1,763	292.6
9 ^{bc}	1,305	1,627	477.8
10 ^b	1,275	2,046	352.5
11 ^b	984	1,965	290.6
12 ^b	1,107	1,910	321.2

^aValues are least squares means of eight pigs per treatment. Pigs on 0 g MBM/kg diet had zero MBM contribution to ME_n intake, and three levels of MBM inclusion (0, 50, and 100 g/kg) were used in the analysis.

^bLinear effect of meat and bone meal, $P < 0.05$.

^cQuadratic effect of meat and bone meal, $P < 0.05$.

and ash contents were not significant ($P > 0.10$; Table 8). The 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 ($P < 0.10$).

Very weak predictive relationships were observed between ME or ME_n and any one of the individual chemical components, as reflected by their low R^2 (equations not shown). As expected, the greatest variation in ME was accounted for using a combination of CP, CF, P, Ca, and ash contents of MBM (Table 9), described by the regression equation $ME = 6,982 + 0.283 \text{ GE (kcal/kg)} - 6.26 \text{ CP (g/kg)} - 3.75 \text{ CF (g/kg)} + 129.47 \text{ P (g/kg)} - 54.91 \text{ Ca (g/kg)} - 6.57 \text{ ash (g/kg)}$, with R^2 of 0.612 and SD of 376 (ME Equation 1; Table 9). The corresponding

Table 7. Apparent ME and N-corrected ME (ME_n) of 12 samples of meat and bone meal (MBM)

MBM Sample No.	ME, kcal/kg of DM	SE	ME_n , kcal/kg of 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

equation for ME_n was $ME_n = 3,937 + 1.089 \text{ GE (kcal/kg)} - 8.74 \text{ CP (g/kg)} + 3.58 \text{ CF (g/kg)} + 60.89 \text{ P (g/kg)} - 15.92 \text{ Ca (g/kg)} - 9.57 \text{ ash (g/kg)}$, with R^2 of 0.811 and SD of 314 (ME_n Equation 1; Table 9). Simpler regression equations describing variation in ME and ME_n were $9,254 - 7.41 \text{ CP (g/kg)} - 9.41 \text{ ash (g/kg)}$, with R^2 of 0.504 and SD of 278 (ME Equation 6; Table 9) and $12,504 - 10.71 \text{ CP (g/kg)} - 13.44 \text{ ash (g/kg)}$, with R^2 of 0.723 and SD of 249 (ME_n Equation 7; Table 9). In general, 52 and 70% 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 described the variation in ME and ME_n of MBM relative to chemical composition. Because feed accounts for more than 60% 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 effect 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 large variability in ME contents. This was important to relate the variability in ME to variation in chemical components, and it resulted in a wide range in ME and ME_n .

The chemical composition of the MBM samples used in this study is similar to values 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) reported chemical compositions of MBM that were similar to our samples. In contrast, Sartorelli et al. (2003) reported relatively lower values for CP and GE but relatively higher values for percentage of ash, P, and Ca than the MBM used in the current studies. The MBM samples in Sartorelli et al. (2003) had a lower Ca:P ratio (1.59 to 2.13) than found in the MBM we used (Ca:P ratio from 2.12 to 2.42). According to the definition of Scott and Dean (1991), four of our MBM samples would not be MBM due to the P concentration being lower than 4%. As percentage of ash increased, GE decreased, which agrees with the observations of Wang and Parsons (1998).

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 would influence its digestibility for nonruminants (Parsons et al., 1997; Wang and Parsons, 1998; Kirstein, 1999). The MBM samples in this study were selected to maximize variability. The variation in individual chemical components of MBM alone accounted for only a small and

Table 8. Pearson correlation coefficients between components of 10 samples of meat and bone meal^a

Item	ME	ME _n	GE	CP	Crude fat	P	Ca
ME _n	0.853						
<i>P</i> -value	0.001						
GE	0.336	0.541					
<i>P</i> -value	0.342	0.106					
CP	-0.177	-0.222	0.613				
<i>P</i> -value	0.624	0.538	0.059				
Crude fat	0.323	0.686	0.295	-0.405			
<i>P</i> -value	0.363	0.029	0.409	0.245			
P	-0.432	-0.472	-0.902	-0.612	-0.148		
<i>P</i> -value	0.212	0.168	<0.001	0.059	0.683		
Ca	-0.511	-0.523	-0.871	-0.532	-0.196	0.989	
<i>P</i> -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
<i>P</i> -value	0.188	0.111	<0.001	0.076	0.647	<0.001	<0.001

^aSample Nos. 1 and 2 were excluded from the analyses; ME_n = N-corrected ME; CP = N × 6.25.

insignificant proportion of the variability in the ME or ME_n.

The energy needs of nonruminants form the cornerstone of diet formulation (Ewan, 2001). Metabolizable energy is used for maintenance, growth, and production. Excess AA are deaminated, with the N excreted and the carbon skeleton metabolized in cells to generate energy; however, this process consumes energy. In the current study, CP concentrations were identical, so energy use would be an accurate comparison. Energy use in this study, irrespective of the level of MBM substitu-

tion, was approximately 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 dietary ME_n showed that most of the pigs retained N. This is an indication that the energy supplied by the MBM is as well utilized as that in the basal diet (based on corn and SBM).

The variation in the ME and ME_n values of the MBM is important when determining the quantity of MBM to be included in the diet. The ME and ME_n values in

Table 9. Intercept, regression coefficients, coefficient of determination, and standard deviation of the equations relating ME and N-corrected metabolizable energy (ME_n) to components of meat and bone meal^a

	Intercept	Regression coefficients						SD	R ²
		GE	CP	CF	P	Ca	Ash		
ME equations									
1	6,982	0.283	-6.26	-3.75	129.47	-54.91	-6.57	376	0.612
2	4,902	0.748	-7.45	-5.47	108.7	-55.1		329	0.603
3	11,858	-0.341	-7.89	-1.65			-12.01	324	0.520
4	12,316	-0.556	-7.03				-12.71	296	0.518
5	10,561		-8.69	-2.95			-10.44	296	0.518
6	9,254		-7.41				-9.41	278	0.504
7	7,667		-6.02	-2.40	74.14	-47.62		302	0.582
8	6,576		-4.85		82.48	-49.23		279	0.573
9	3,050			1.69	162.1	-75.81		300	0.504
ME _n equations									
1	3,937	1.089	-8.74	3.58	60.89	-15.92	-9.57	314	0.811
2	906	1.766	-10.47	1.07	30.62	-16.16		281	0.798
3	4,532	1.116	-10.13	3.12			-5.71	248	0.803
4	-78.43	2.117	-11.66					220	0.784
5	3,664	1.525	-11.76				-4.38	230	0.798
6	8,780		-7.50	7.41			-10.84	238	0.783
7	12,504		-10.71				-13.44	249	0.723
8	2,583			14.22			-5.76	278	0.653
9	7,434		-7.10	8.33	-51.02	1.43		298	0.717
10	11,219		-11.18		7.00	-79.96		305	0.642
11	1,993			13.15	52.65	-31.78		306	0.641

^aSample Nos. 1 and 2 were excluded from the analyses; ME (kcal/kg), ME_n = N-corrected ME (kcal/kg), GE (kcal/kg), CP (N × 6.25, g/kg), CF = crude fat (g/kg), P (g/kg), Ca (g/kg), and ash (g/kg).

this study were similar to those reported by Shi and Noblet (1993) 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, and the use of GE or CP and CF also gave reliable values. They also observed, however, that the difference in MBM digestibility could not be accounted for solely by the variation in the chemical constituents of the MBM. Due to greater GE and lower ash, it would be expected that MBM Sample 2 would give a greater ME and ME_n than Sample 1; however, the opposite was the case in this study. One explanation for the low ME value of Sample 2 could be 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 Sample 2 to diet ME was relatively small compared with the other MBM samples. Pigs on 8 of the 12 MBM samples retained N, as reflected by the lower ME_n values.

A number of factors may be responsible for the 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; Leeson and Summers, 2001). Unsaturated fats have more rancidity problems affecting consumption and use.

The results presented in this study indicate the individuality of GE, CP, and CF of the MBM are not proportional to the ME or ME_n of the MBM. Interactions of these components of the MBM, along with other factors such as quality of the MBM, determine the energy in MBM that is metabolized by pigs.

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