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Non ruminant nutrition

Digestibility of energy and concentrations of metabolizable energy and net energy varies among sources of bakery meal when fed to growing pigs

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Abstract

The null hypothesis that there are no differences in concentrations of digestible energy (**DE**), metabolizable energy (**ME**), and net energy (**NE**) among different sources of bakery meal was tested in a regional experiment involving 5 of the universities on the North Central Coordinating Committee-42 on Swine Nutrition. Eleven sources of bakery meal were procured from the swine producing areas in the United States and included in one diet as the only energy containing ingredient, and each diet was then divided into 5 batches that were used at the University of Illinois, Purdue University, University of Kentucky, University of Nebraska, and North Carolina State University. At each university, diets were fed to 22 growing pigs (2 pigs per diet) that were placed in metabolism crates, and feces and urine were collected for 5 d after a 7-d adaptation period. Diets and collected samples of feces and urine were dried and analyzed for gross energy. The apparent total tract digestibility of dry matter (**DM**) and gross energy and concentrations of DE, ME, and NE were calculated. Results indicated that there were considerable variation in the nutritional composition among the different sources of bakery meal with relatively large coefficients of variation for crude protein, starch, and acid hydrolyzed ether extract, but it was possible to analyze all sources of bakery meal to account for 100% of the ingredients. The average DE, ME, and NE in the 11 sources of bakery meal was 3,827, 3,678, and 2,799 kcal/kg DM, respectively. However, in contrast to the hypothesis, differences ($P < 0.05$) among sources of bakery meal in concentrations of DE (3,827 ± 201 kcal/kg DM), ME 3,678 ± 200 kcal/kg DM), and NE (2,799 ± 156 kcal/kg DM) were observed, but the variation among the 11 sources of bakery meal was not greater than what is usually observed among different sources of other ingredients. The differences observed are likely a consequence of the different product streams and production procedures used to produce the bakery meal. In conclusion, the average DE, ME, and NE in 11 sources of bakery meal is close to values previously reported, but there is some variation among sources depending on origin.

Lay Summary

An experiment was conducted at 5 universities to determine digestible energy (DE), metabolizable energy (ME), and net energy (NE) by growing pigs in 11 sources of bakery meal that were sourced from swine producing states in the United States. Each source was analyzed and included in a diet as the only source of energy. Diets were fed to growing pigs that were housed in metabolism crates and fecal and urine samples were collected. Values for DE and ME were calculated from analyzed energy in diets, feces, and urine, and NE was calculated using a prediction equation. Results indicated that it was possible to analyze each source of bakery meal to 100%. The average DE, ME, and NE was 3,827, 3,678, and 2,799 kcal/kg dry matter. Although some variability among the 11 sources of bakery meal was observed, the variability in DE and ME values in bakery meal was not greater than what is observed in most other normally used feed ingredients.

Key words: bakery meal, digestible energy, metabolizable energy, net energy, pigs

Abbreviations: ATTD, apparent total tract digestibility; DE, digestible energy; DM, dry matter; GE, gross energy; ME, metabolizable energy; ND, not detectable; NE, net energy

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Introduction

The importance of identifying feed ingredients for livestock production that do not compete with food for humans has been demonstrated recently because of the elevated prices of cereal grains, specifically wheat. However, large quantities of food for humans cannot be used for their intended purposes, but may be used in animal feed (Jinno et al., 2018; Shurson, 2020). If all non-usable food items are utilized in animal feeding they may contribute up to 15% of the total feed needed for livestock (Sandström et al., 2022), but there are considerable challenges involved with inclusion of these foods into animal feeds. Under practical conditions, it is primarily dried ingredients that are included in diets for pigs and in the United States, these dried non-usable food items are marketed under the general name bakery meal. In a study involving 46 sources of bakery meal collected in the United States, it was demonstrated that despite the different product streams that may be used in bakery meal, the chemical composition generally is consistent among different sources of bakery meal (Liu et al., 2018). It is, therefore, hypothesized that the nutritional value of bakery meal is constant as well. The digestibility of amino acids and phosphorus in bakery meal has been determined in several experiments (Almeida et al., 2011; Rojas et al., 2013; Casas et al., 2015, 2018a; Luciano et al., 2022). However, to our knowledge, there is only one recent experiment in which digestible energy (**DE**) and metabolizable energy (**ME**) were determined and only one source of bakery meal was included in that experiment (Rojas et al., 2013). Therefore, the objective of this research was to test the null hypothesis that apparent total tract digestibility (**ATTD**) of gross energy (**GE**) and concentrations of DE, ME, and net energy (**NE**) in bakery meal are not different among different origins regardless of where in the United States they are collected.

Materials and Methods

Animals, Housing, Diets, Feeding, and Sample Collection

The experiment was conducted as part of the research efforts of the North Central Coordinating Committee 42 and the following 5 universities participated in the experiment: University of IL, Urbana-Champaign, IL, USA; Purdue University, West Lafayette, IN, USA; North Carolina State University, Raleigh, NC, USA; University of Nebraska, Lincoln, NE, USA; and University of Kentucky, Lexington KY, USA. A protocol for the animal work was submitted to and approved by the Institutional Animal Care and Use Committee at each participating university before the animal work was initiated. Pigs used at the University of Illinois were the offspring of Line 359 boars mated to Camborough females (Pig Improvement Company, Henderson, TN, USA); pigs used at Purdue University were Duroc males mated to Yorkshire × Landrace females; pigs used at North Carolina State University were internally bred from Smithfield Premium Genetics (Roanoke Rapids, NC, USA); pigs used at University Nebraska were the offspring of a Danbred boar mated to a Nebraska White Line sow; and pigs used at the University Kentucky were the offspring of Chester White males mated to Yorkshire × Landrace females.

Eleven sources of bakery meal were collected from feed mills located in the swine producing states in the United States and shipped to the University of Illinois. The 11 sources used were identical to the bakery meals used in an experiment to determine the standardized ileal digestibility of amino acids in bakery meal (Stein et al., 2023). Upon arrival at the University of Illinois, each source of bakery meal was immediately labelled and a sub-sample was collected for analysis (Table 1). Eleven diets were prepared by mixing each source of bakery meal with minerals and vitamins, and bakery meal was, therefore, the only energy contributing ingredient in each diet. Vitamins and minerals were included in each diet to meet current requirement estimates for growing pigs (NRC, 2012). Each diet was prepared in one batch and each batch was subsequently divided into 5 sub-batches (Tables 2 and 3). One batch was used at the University of Illinois, whereas the remaining four sub-batches were shipped to the other participating universities.

At each university, 22 barrows (average initial body weight: 24.5 ± 4.28 kg) were randomly allotted to the 11 diets with 2 pigs per diet. Pigs were housed individually in metabolism crates that were equipped with a self-feeder, a nipple waterer, and a slatted floor. A screen and a urine pan were placed under the slatted floor to allow for the total, but separate, collection of urine and fecal materials. Pigs were limit fed at 3.3 times the energy requirement for maintenance (i.e., 197 kcal ME per kg $BW^{0.60}$; NRC, 2012), which is considered to be close to the ad libitum intake of growing pigs (NRC, 2012). The calculated ME of all diets was 3,335 kcal/kg. Feed was provided each day in 2 equal meals at 0800 and 1600 hours. Throughout the experiment, pigs had ad libitum access to water. Feed consumption was recorded daily, and diets were fed for 14 d. The initial 7 d were considered the adaptation period to the diet, whereas urine and fecal material were collected from the feed provided during the following 5 d according to the marker to marker approach (Adeola, 2001). Chromic oxide was used as the start marker and provided in the morning meal on day 8 and ferric oxide was used as the stop marker and provided in the morning meal on day 13. Fecal sample collection was initiated when chromic oxide was detected in the feces, i.e., when the feces turned green, and ceased when ferric oxide first appeared in the feces, i.e., when feces turned dark. Fecal samples were collected in the morning and in the afternoon during the collection period and all collected fecal samples were stored at – 20 °C. Urine was collected in urine buckets over a preservative of 50 mL of 3*N* hydrochloric acid. Buckets were placed under the metabolism crates at 9:00 AM on day 8 and collection of urine ceased at 9:00 AM on day 13. Each morning on days 9, 10, 11, 12, and 13, the weight of the urine in the buckets was recorded and 10% of the collected urine was stored at – 20 °C immediately after collection. At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet, and a sub-sample was lyophilized before analysis (Kim et al., 2009). Unconsumed feed was collected on days 9, 10, 11, 12, and 13. This feed was dried and the weight and dry matter were recorded. Fecal samples were thawed and mixed within pig and diet at the conclusion of the collection period, and then dried in a forced air drying oven (temperature range: 50 to 55 °C) and ground.

Sample Analysis

Dry matter in the 11 sources of bakery meal, all diets, and oven-dried fecal samples was measured using a drying oven for 2 h at 135 °C (method 930.15; AOAC Int., 2019). Ash in ingredient and diet samples was also analyzed (method 942.05; AOAC Int., 2019). Crude protein in ingredient and diet samples was

Table 1. Nutrient composition of 11 sources of bakery meal[1,2]

Item, %	Bakery meal source											Average	CV
	A	B	C	D	E	F	G	H	I	J	K		
Dry matter	89.90	90.06	88.99	90.11	88.67	88.49	88.43	89.25	84.88	86.47	90.18	88.68	1.9
Gross energy, kcal/kg	4,042	4,180	3,926	4,157	3,997	3,907	4,225	4,174	4,130	3,687	4,099	4,048	3.9
Crude protein	10.75	11.57	8.68	12.88	12.97	10.92	12.05	12.16	13.50	7.46	12.26	11.38	16.3
Acid hydrolyzed ether extract	7.61	8.38	5.77	8.64	5.02	4.09	8.73	9.63	5.59	5.33	10.16	7.18	29.0
Ash	4.94	3.44	6.91	4.45	5.02	4.98	3.42	4.54	4.08	10.26	5.47	5.23	36.9
Starch	40.04	38.63	38.81	35.64	35.99	41.36	37.05	44.88	30.89	38.37	35.82	37.95	9.5
Acid detergent fiber	5.76	4.26	9.13	5.92	9.23	5.32	3.70	5.02	8.13	4.12	7.41	6.18	32.3
Total dietary fiber	16.70	15.14	19.08	17.29	18.76	14.42	13.34	11.54	18.66	11.09	14.05	15.46	18.5
Insoluble dietary fiber	15.17	13.29	17.60	15.72	18.26	13.03	12.34	10.55	18.04	9.16	14.05	14.29	21.0
Soluble dietary fiber	1.57	1.86	1.48	1.56	0.50	1.39	1.00	0.99	0.62	1.93	ND	1.29	51.9
Sugars													
Glucose	2.71	1.76	2.83	1.29	1.42	3.00	3.13	1.19	1.50	1.62	1.62	2.01	0.75
Fructose	1.73	2.26	1.37	0.93	0.75	2.07	2.81	1.37	1.13	0.91	0.91	1.48	0.66
Maltose	2.61	6.11	6.71	3.25	2.82	9.22	6.17	3.15	3.70	4.14	5.59	4.86	2.07
Sucrose	4.24	2.93	3.54	3.08	1.67	3.75	3.53	0.64	6.52	9.73	3.00	3.88	2.43
Raffinose	0.10	0.23	0.19	0.32	0.17	0.15	0.29	ND	ND	0.05	0.17	0.19	0.09
Stachyose	0.13	ND	ND	0.07	0.16	0.15	ND	ND	ND	ND	0.30	0.16	0.09
Rest fraction[3]	−4.05	−2.78	−6.69	0.18	3.69	−6.94	−2.86	−1.25	2.76	−1.09	−1.53	−1.87	180
Indispensable AA													
Arg	0.53	0.58	0.47	0.63	0.67	0.60	0.60	0.50	0.73	0.35	0.67	0.58	18.7
His	0.24	0.26	0.20	0.27	0.30	0.26	0.27	0.27	0.32	0.15	0.29	0.26	18.2
Ile	0.45	0.44	0.35	0.45	0.55	0.45	0.45	0.49	0.57	0.39	0.53	0.47	14.3
Leu	0.82	0.80	0.63	0.86	1.03	0.84	0.82	0.92	1.06	0.66	0.96	0.85	15.7
Lys	0.40	0.34	0.32	0.46	0.51	0.41	0.37	0.38	0.48	0.26	0.58	0.41	21.9
Met	0.17	0.19	0.15	0.19	0.19	0.19	0.18	0.21	0.20	0.11	0.20	0.18	15.5
Phe	0.52	0.51	0.42	0.52	0.61	0.54	0.53	0.58	0.67	0.46	0.60	0.54	13.3
Thr	0.34	0.35	0.27	0.37	0.43	0.36	0.36	0.36	0.47	0.27	0.44	0.37	16.9
Trp	0.12	0.15	0.10	0.13	0.13	0.11	0.17	0.13	0.15	0.10	0.16	0.13	17.4
Val	0.53	0.54	0.42	0.56	0.63	0.53	0.54	0.55	0.74	0.43	0.60	0.55	16.0
Dispensable AA													
Ala	0.47	0.48	0.39	0.54	0.63	0.48	0.48	0.46	0.73	0.38	0.56	0.51	20.0
Asp	0.75	0.70	0.61	0.79	1.01	0.80	0.72	0.68	0.92	0.56	1.06	0.78	20.3
Cys	0.23	0.27	0.19	0.23	0.25	0.25	0.27	0.27	0.23	0.15	0.21	0.23	15.8
Glu	2.54	2.83	1.99	2.46	2.61	2.62	3.03	3.32	1.88	1.23	2.56	2.46	23.5
Gly	0.46	0.52	0.40	0.51	0.58	0.49	0.53	0.45	0.65	0.34	0.53	0.49	17.2
Pro	0.85	0.93	0.64	0.83	0.86	0.83	0.99	1.16	0.65	0.40	0.81	0.81	24.5
Ser	0.44	0.44	0.34	0.45	0.50	0.46	0.47	0.49	0.51	0.30	0.51	0.44	15.6
Tyr	0.33	0.33	0.28	0.33	0.41	0.35	0.35	0.38	0.80	0.84	0.37	0.43	44.8
Total AA	10.4	10.9	8.4	10.8	12.1	10.8	11.3	11.9	12.0	7.6	11.9	10.7	13.8
Lys to crude protein ratio	3.59	2.83	3.55	3.86	3.82	2.95	3.27	3.09	3.73	3.24	4.73	3.51	15.2

[1] All values except dry matter were adjusted to 88% dry matter basis.
[2] ND = not detectable.
[3] Rest fraction was calculated as dry matter - (crude protein + acid hydrolyzed ether extract + ash + total dietary fiber + starch + glucose + fructose + maltose + sucrose + stachyose + raffinose).

calculated as N × 6.25 and N was measured using the combustion procedure (method 990.03; AOAC Int., 2019) on a LECO FP628 (LECO Corp., Saint Joseph, MI). The 11 sources of bakery meal, the 11 diets, fecal samples, and urine samples were analyzed for gross energy (**GE**) using bomb calorimetry (Model 6400; Parr Instruments, Moline, IL).

Amino acids in the 11 bakery meals were analyzed on a Hitachi Amino Acid Analyzer (Model No. L8800; Hitachi High Technologies America, Inc.; Pleasanton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard [method 982.30 E(a, b, c); AOAC Int., 2019].

Acid-hydrolyzed ether extract in the 11 sources of bakery meal was analyzed by 3*N* HCl hydrolysis (Ankom^{HCl}, Ankom Technology, Macedon, NY) followed by crude fat extraction using petroleum ether (method 2003.06; AOAC Int., 2019) on an Ankom fat analyzer (AnkomXT15, Ankom Technology, Macedon, NY, USA). To determine fatty acids in crude fat on a percentage basis, ether extract in the 11 sources of bakery meal was also determined [Method

920.39 (A); AOAC Int., 2019]. Methyl esters of fatty acids were extracted from the bakery meal samples (Method Ce 2-66; AOCS, 2017), and the concentration of fatty acids in these samples was measured using capillary gas liquid chromatography (Method 996.06; AOAC Int., 2019). Total starch in each source of bakery meal was analyzed by the glucoamylase procedure (method 979.10; AOAC Int., 2019) and acid detergent fiber in these ingredients was analyzed using Ankom Technology method 12 (Ankom 2000 Fiber Analyzer, Ankom Technology, Macedon, NY). Insoluble and soluble dietary fiber in the 11 sources of bakery meal were analyzed according to method 991.43 (AOAC Int., 2019) using the Ankom$^{\text{TDF}}$ Dietary Fiber Analyzer (Ankom Technology, Macedon, NY). Bakery meal samples were analyzed for sugars including glucose, fructose, maltose, sucrose, stachyose, and raffinose using high-performance liquid chromatography (Dionex App Notes 21 and 92).

Calculations and Statistical Analysis

For each source of bakery meal, all proximate components were summarized and subtracted from the concentration of dry matter in each sample to calculate the rest fraction according to the following equation:

Rest fraction = [dry matter - (crude protein + acid hydrolyzed ether extract + ash + total dietary fiber + total starch + glucose + fructose + maltose + sucrose + stachyose + raffinose)].

Orts collected from days 8 to 13 were subtracted from the total amount of feed provided to each pig to calculate total feed intake. Following sample analysis, the ATTD of GE and dry matter were calculated for each diet, and the DE and ME in each diet were calculated as well. The DE and ME of each source of bakery meal were then calculated by dividing the DE and ME of the diet by the inclusion rate of bakery meal the diet (i.e., 98.25%). Net energy in each source of bakery meal was then calculated from ME and analyzed nutrient composition according to the following equation (Noblet et al., 1994):

NE = (0.726 × ME) + (1.33 × ether extract) + (0.39 × starch) − (0.62 × crude protein) − (0.83 × acid detergent fiber),

where NE is expressed as kcal/kg dry matter and all nutrient contents are expressed as g/kg dry matter.

Table 2. Ingredient composition of experimental diets, as-fed basis

Item	Bakery meal[1]
Bakery meal	98.25
Ground limestone	0.30
Dicalcium phosphate	0.90
Sodium chloride	0.40
Vitamin–mineral premix[2]	0.15

[1] Eleven diets were formulated using 11 different sources of bakery meal.

[2] The vitamin–micromineral premix provided the following quantities of vitamins and micro minerals per kg of complete diet: vitamin A as retinyl acetate, 11,150 IU; vitamin D_3 as cholecalciferol, 2,210 IU; vitamin E as DL-α-tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfate, 1.42 mg; thiamin as thiamine mononitrate, 1.10 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 1.00 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.6 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper chloride; Fe, 125 mg as iron sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese hydroxychloride; Se, 0.30 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc hydroxychloride.

Data were analyzed using the PROC GLM of SAS (SAS Institute Inc., Cary, NC). Homogeneity of the variances was confirmed. Diet, university, and the interaction between diet and university were the fixed effects. However, no interactions between diet and university were observed, and the final model, therefore, only included diet and university as fixed effects. Pig was the experimental unit for all analyses. Means were calculated and the least significant difference was used to separate means. Results were considered significant at $P \leq 0.05$.

Results

Concentrations of dry matter (**DM**) in the 11 sources of bakery meal ranged from 84.88% to 90.18% (Table 1). When adjusted to 88% DM, concentration of GE ranged from 3,687 to 4,225 kcal/kg with an average of 4,048 kcal/kg. The 11 sources of bakery meal contained 7.46% to 13.50% crude protein with an average of 3.51% for the Lys to crude protein ratio and the average acid hydrolyzed ether extract was 7.18%. The concentration of total dietary fiber ranged from 11.09% to 19.08%. The sucrose concentration averaged 3.88% and ranged from <1% to almost 10% and maltose ranged from 2.61% to 9.22% with an average of 4.86%. The calculated rest fraction was negative for most sources of bakery meal and the average rest fraction was −1.87%. Approximately 58.03% of total ether extract consisted of monounsaturated fatty acids, whereas the average concentrations of saturated fatty acids and polyunsaturated fatty acids were 15.42% and 20.83%, respectively (Table 4).

One pig fed the diet containing bakery meal source H did not complete the collection period at one of the universities and data for this pig, therefore were not included in the final analysis, and as a consequence, there were only 9 observations for this diet. Feed intake of pigs ranged from 1.00 to 1.15 kg/d and GE intake ranged from 4,043 to 4,737 kcal/d (Table 5). Dry feces output ranged from 0.12 to 0.21 kg/d and GE fecal excretion ranged from 571 to 925 kcal/d. The ATTD

Table 3. Analyzed nutrient composition of diets containing bakery meal, as-fed basis

Item	Bakery meal diet										
	A	B	C	D	E	F	G	H	I	J	K
Dry matter, %	89.98	90.23	89.44	90.49	88.58	87.99	87.99	89.06	85.94	86.77	90.38
Ash, %	6.40	5.39	6.37	6.24	6.49	6.35	4.96	6.03	5.27	11.51	7.28
Crude protein, %	10.75	11.57	8.68	12.88	12.97	10.92	12.05	12.16	13.50	7.46	12.26
Gross energy, kcal/kg	4,076	4,210	3,923	4,180	3,969	3,839	4,182	4,212	3,948	3,623	4,128

Table 4. Fatty acid composition in 11 sources of bakery meal (% of ether extract)[1,2]

Item, %	Bakery meal source											Average	CV
	A	B	C	D	E	F	G	H	I	J	K		
Saturated fatty acids													
C14:0	1.52	0.64	1.08	0.77	1.71	ND[2]	ND	ND	ND	ND	1.36	1.18	106.5
C15:0	0.11	0.09	0.09	0.07	0.14	ND	ND	ND	ND	ND	0.11	0.10	100.7
C16:0	18.68	17.95	22.20	15.56	18.43	0.36	0.29	0.72	0.22	0.22	16.06	10.06	93.8
C17:0	0.22	0.19	0.14	0.12	0.20	0.18	0.13	0.19	0.21	0.21	0.19	0.18	19.3
C18:0	7.62	4.34	4.70	6.35	5.87	0.13	0.15	0.59	0.38	ND	6.53	3.66	82.6
C20:0	0.53	0.41	0.42	0.39	0.48	0.43	0.50	0.44	0.44	0.40	0.60	0.46	14.3
C21:0	0.18	0.11	0.09	0.11	0.10	0.16	0.15	0.23	0.10	0.06	0.14	0.13	36.3
C22:0	0.36	0.26	0.36	0.33	0.45	0.48	0.27	0.29	0.28	0.28	0.34	0.34	21.3
C24:0	0.23	0.19	0.24	0.22	0.39	0.24	0.15	0.14	0.24	0.22	0.27	0.23	28.7
Total	29.43	24.16	29.30	23.92	27.75	1.97	1.63	2.59	1.87	1.40	25.60	15.42	84.8
Monounsaturated fatty acids													
C14:1n5	ND	ND	ND	ND	ND	0.10	0.09	0.22	0.08	0.09	ND	0.12	133.5
C15:1n5	ND	ND	ND	ND	ND	23.28	19.43	21.03	18.48	19.40	ND	20.32	115.6
C16:1n7	0.44	0.38	0.32	0.25	0.40	0.16	0.13	0.27	0.20	0.22	0.35	0.28	36.0
C17:1n7	0.19	0.20	0.17	0.11	0.14	5.28	5.29	7.35	6.50	9.15	0.20	3.14	113.6
C18:1n9t [Elaidic]	0.23	0.21	0.25	0.15	0.39	26.25	30.38	27.89	32.03	29.46	0.37	13.42	113.1
C18:1 [Oleic]	29.39	33.29	25.27	28.34	28.03	1.64	1.64	1.49	1.78	1.85	28.92	16.51	86.7
C18:1n7c [Cis-vaccenic]	1.46	1.59	1.49	1.33	1.56	31.55	32.76	26.55	33.42	29.65	1.39	14.80	104.2
C20:1n9 [Gondoic]	0.49	0.51	0.39	0.50	0.45	0.45	0.56	0.46	0.51	0.42	0.42	0.47	10.7
C22:1n9 [Erucic]	0.04	0.03	0.05	0.25	0.14	0.05	0.05	0.07	0.03	0.02	0.02	0.07	102.6
C24:1n9 [Nervonic]	0.05	0.08	0.06	0.06	0.05	0.06	0.05	0.03	0.05	0.05	0.03	0.05	26.6
Total	32.29	36.28	27.98	30.99	31.14	88.82	90.38	85.35	93.10	90.31	31.70	58.03	52.3
Polyunsaturated fatty acids													
C18:2n6 [Linoleic]	27.63	31.45	34.40	36.91	31.77	ND	ND	ND	ND	ND	33.67	32.62	96.6
C18:3n3 [a-Linolenic]	3.20	3.16	2.32	2.97	2.41	2.26	3.62	2.61	3.00	3.21	2.15	2.81	17.2
C20:2	0.07	0.08	0.16	0.09	0.41	0.26	0.10	0.22	0.08	0.08	0.19	0.16	67.0
C20:4n6 [Arachidonic]	0.02	0.06	ND	0.05	0.06	0.03	0.08	0.08	0.03	0.02	0.03	0.03	61.9
C20:3n3	0.02	0.04	ND	0.03	0.04	0.03	0.02	0.03	ND	ND	ND	0.02	85.9
Total	30.94	34.78	36.88	40.04	34.68	2.58	3.82	2.94	3.11	3.31	36.04	20.83	81.9

[1] All values were adjusted to 88% dry matter basis.
[2] ND = not detectable.

of DM and GE ranged from 80.0% to 87.5% and from 79.8% to 87.0%, respectively. The average concentration of DE in diets was 3,343 kcal/kg (as-fed basis), and the SD was 195 kcal/kg. Urine GE output ranged from 106 to 163 kcal/d. The average concentration of ME in diets was 3,213 kcal/kg (as-fed basis), and the SD was 197 kcal/kg.

Concentrations of DE in the 11 sources of bakery meal ranged from 3,150 to 3,728 kcal/kg (as-fed basis), ME ranged from 3,013 to 3,578 kcal/kg (as-fed basis), and NE ranged from 2,295 to 2,759 kcal/kg (as-fed basis; Table 6). Average concentrations (as-fed basis) of DE, ME, and NE in the 11 sources of bakery meal were 3,402, 3,270, and 2,483 kcal/kg, respectively. The ATTD of GE (i.e., DE to GE) ranged from 80.0% to 88.1%; metabolizability of DE (i.e., ME to DE) ranged from 95.0% to 96.8%; metabolizability of GE (i.e., ME to GE) ranged from 76.6% to 84.5%. The NE to ME ratio ranged from 75.1% to 77.4% and NE to GE ranged from 57.6% to 65.2%.

The average CV for GE, DE, and ME (DM-basis) in bakery meal was 3.94%, 5.25%, and 5.44%, respectively (Table 7). These values are within the range of CV for GE, DE, and ME, observed in other ingredients fed to growing pigs.

Discussion

The concentration of GE in the bakery meal samples used in the experiment was in very good agreement with the gross energy reported in other sources of bakery meal (Rojas et al., 2013; Zhang and Adeola, 2017; Liu et al., 2018). Dry matter was less than in bakery meal used in some previous studies (Arosemena et al., 1995; Slominski et al., 2004; NRC, 2012; Casas et al., 2018a; Liu et al., 2018), but in good agreement with other previously used sources (Rojas et al., 2013; Casas et al., 2015). It therefore appears that there may be some variation in DM among sources of bakery meal, which likely is a consequence of the different product streams that may be used in bakery meal. The average concentration of starch (37.95%) is close to values reported previously (Slominski et al., 2004; Rojas et al., 2013; Casas et al., 2018a; Liu et al., 2018), but the

Table 5. Effect of sources of bakery meal on apparent total tract digestibility (ATTD) of dry matter and gross energy and concentrations of digestible energy (DE) and metabolizable energy (ME) in diets containing 11 different sources of bakery meal (as-fed basis)[1]

Item	Bakery meal											Average	Diet		
	A	B	C	D	E	F	G	H	I	J	K		SEM	LSD	*P*-value
Observation, *n*	10	10	10	10	10	10	10	9	10	10	10	-	-	-	-
Intake															
Feed intake, kg/d	1.00	1.07	1.13	1.11	1.14	1.13	1.09	1.05	1.10	1.12	1.15	1.10	0.04	0.11	0.284
Gross energy, kcal/d	4,075	4,518	4,450	4,653	4,523	4,320	4,564	4,404	4,352	4,043	4,737	4,422	154	437	0.050
Fecal excretion															
Dry feces output, kg/d	0.16	0.15	0.19	0.21	0.21	0.17	0.14	0.12	0.18	0.16	0.20	0.17	0.01	0.03	<0.001
Gross energy, kcal/d	702	679	801	925	910	725	669	571	888	586	866	756	47	134	<0.001
ATTD, %															
Dry matter	82.9	85.3	82.0	80.8	80.0	84.0	86.6	87.5	82.5	84.5	82.3	83.5	0.7	1.9	<0.001
Gross energy	82.8	85.0	81.7	80.6	79.8	83.3	85.5	87.0	80.1	85.4	82.0	83.0	0.7	2.0	<0.001
DE in diet, kcal/kg	3,376	3,579	3,206	3,369	3,166	3,197	3,574	3,663	3,162	3,095	3,385	3,343	29	81	<0.001
Urine excretion															
Urine output, kg/d	3.02	4.03	2.61	2.43	2.99	2.93	3.09	4.90	4.46	3.58	4.53	3.51	0.73	2.09	0.333
Gross energy, kcal/d	106	136	128	113	140	136	134	139	163	140	122	133	10	28	0.013
ME in diet, kcal/kg	3,258	3,452	3,082	3,260	3,030	3,068	3,442	3,516	3,005	2,960	3,273	3,213	29	84	<0.001

[1] Main effect of diet. No diet × university interactions were observed.

CV of 9.5% indicates quite some variation in the starch concentration in bakery meal. This is likely a consequence of different inclusion rates of ingredients produced from wheat flour because some sources of bakery meal may contain greater quantities of bread and breakfast cereals, which have high concentrations of starch, whereas other sources of bakery meal may contain more full grain bread products or grain co-products, which tend to contain less starch and more fiber (Liu et al., 2018). Indeed, there is a negative correlation between the concentration of starch and fiber in bakery meal (Slominski et al., 2004).

The average crude protein (11.65%) is also in agreement with published values (Slominski et al., 2004; Rojas et al., 2013; Zhang and Adeola, 2017; Casas et al., 2018a; Liu et al., 2018), but as for most other nutrients in bakery meal, some variability exists among sources depending on the number and concentration of high protein ingredients being included in the product mix in each source. The concentration of acid hydrolyzed ether extract in bakery meal is generally between 7% and 10% (Rojas et al., 2013; Casas et al., 2015; Liu et al., 2018) and the majority of the values analyzed in the bakery meals used in this experiment are within this range although three sources contained more than 10% acid hydrolyzed ether extract, indicating that these sources contained more high-fat ingredients than the other sources.

The observation that the unsaturated to saturated ratio of fatty acids on average was 1:2.65 indicate that a large part of the fat included in the ingredients was of animal origin because almost all plant oils have much greater ratios between unsaturated and saturated fatty acids (NRC, 2012). The high concentration of lauric acid (C 16:0) further indicates that a large part of the fat was animal fat because lauric acid, with a few exceptions, is present in lower concentrations in plant oils.

Overall, the concentration of most nutrients in the bakery meals used in this experiment is within the range of reported values. However, because commercially sources of bakery meals are blended products consisting of a number of raw materials in different proportions, some variability in composition is expected, which is also reflected in the relatively large CV for most nutrients. The small negative rest fraction that was observed in most sources of bakery meal indicates that some nutrients may have been slightly overestimated in the analysis or have been included in two different analyses. As an example, it is possible that some of the analyzed maltose may also have been included in the analyzed starch fraction. Nevertheless, the observation that the rest fraction was close to zero or negative indicates that all components in the meals were accounted for in the chemical analyses.

The ATTD for GE in corn usually is around 88%, whereas soybean meal has an ATTD of GE between 82 and 88% (Goebel and Stein, 2011; Rojas and Stein, 2013; Sotak-Peper et al., 2015; Lopez et al., 2020). In contrast, cereal co-products such as rice bran, wheat middlings, and distillers dried grains with solubles have ATTD values for GE that are <80% (Casas and Stein, 2016; Casas et al., 2018b; Espinosa and Stein, 2018). The observation that the average ATTD of GE in the 11 sources of bakery meal used in the experiment (83.4%) is between values for cereal grain co-products and corn indicates that the product mix used in the ingredients included in bakery meal contains a mixture of cereal flour and cereal co-products and possibly some whole grain cereals as well. It is also possible that cereal co-products or soybean meal

Table 6. Concentrations of digestible energy (DE), metabolizable energy (ME), and net energy (NE) in 11 sources of bakery meal[1]

Item	Bakery meal											Mean	Ingredient		
	A	B	C	D	E	F	G	H	I	J	K		SEM	LSD	*P*-value
Observation, *n*	10	10	10	10	10	10	10	9	10	10	10	—	—	—	—
As-fed basis, kcal/kg															
DE	3,436	3,642	3,263	3,429	3,222	3,254	3,638	3,728	3,218	3,150	3,445	3,402	29	83	<0.001
ME	3,316	3,513	3,136	3,318	3,084	3,123	3,503	3,578	3,058	3,013	3,331	3,270	30	85	< 0.001
NE	2,568	2,674	2,388	2,504	2,321	2,352	2,638	2,759	2,295	2,307	2,511	2,483	22	62	<0.001
Dry matter basis, kcal/kg dry matter															
DE	3,806	4,046	3,642	3,822	3,633	3,680	4,123	4,172	3,751	3,607	3,814	3,827	33	93	<0.001
ME	3,674	3,903	3,501	3,697	3,477	3,532	3,971	4,004	3,565	3,450	3,688	3,678	34	96	<0.001
NE	2,856	2,970	2,683	2,778	2,617	2,658	2,983	3,091	2,704	2,669	2,784	2,799	25	70	<0.001
Digestibility and metabolizability, %															
DE to GE	83.2	85.1	82.2	80.6	80.0	82.8	85.7	88.1	80.8	87.0	82.0	83.4	0.7	2.1	<0.001
ME to DE	96.5	96.5	96.1	96.8	95.7	96.0	96.3	96.0	95.0	95.6	96.7	96.1	0.3	1.0	0.026
ME to GE	80.3	82.1	79.0	77.9	76.6	79.5	82.5	84.5	76.8	83.2	79.3	80.2	0.7	2.1	<0.001
NE to ME	77.4	76.1	76.1	75.5	75.3	75.3	75.3	77.1	75.1	76.6	75.4	75.9	0.03	0.1	<0.001
NE to GE	62.2	62.5	60.1	58.8	57.6	59.9	62.1	65.2	57.6	63.7	59.8	60.9	0.5	1.5	<0.001

[1] Main effect of ingredient. No ingredient × university interactions were observed.

Table 7. Variation in energy concentrations among different sources of feed ingredients fed to growing pigs

Item	Bakery meal[2]		DDGS[1,3], Low oil		Canola meal[4]		00-rapeseed expellers[4]		00-rapeseed meal[4]		Soybean meal[5]		Sunflower meal[6]		Wheat middlings[7]	
	Mean	CV, %	Mean	CV, %	Mean	CV, %	Mean	CV, %	Mean	CV, %	Mean	CV, %	Mean	CV, %	Mean	CV, %
n	11		8		6		5		11		22		6		10	
DM[1], %	88.68	1.87	85.71	3.45	89.92	0.60	91.84	2.47	88.94	0.79	88.63	0.98	90.47	1.46	88.77	1.17
As-fed basis																
GE[1]	4,080	4.87	4,575	1.35	4,218	0.42	4,721	2.27	4,210	1.33	4,206	2.93	4,324	2.66	3,979	1.96
DE[1]	3,402	5.85	3,126	3.30	3,037	3.45	3,674	4.22	3,071	3.29	3,828	3.48	2,919	5.68	2,654	5.26
ME[1]	3,270	6.12	2,876	4.04	2,784	4.59	3,387	4.83	2,801	3.84	3,694	3.66	2,692	6.85	2,568	5.41
DM-basis																
GE	4,600	3.94	5,343	3.99	4,691	0.79	5,142	3.04	4,734	0.97	4,746	2.70	4,779	1.65	4,482	1.55
DE	3,827	5.25	3,651	5.15	3,378	3.59	4,005	5.91	3,453	3.49	4,319	3.27	3,228	6.25	2,990	5.57
ME	3,678	5.44	3,359	5.63	3,096	4.70	3,691	6.16	3,149	4.09	4,168	3.40	2,977	7.46	2,893	5.75

[1] DDGS = distillers dried grain and solubles; DE = digestible energy; DM = dry matter; GE = gross energy; ME = metabolizable energy.
[2] Data from the current experiment.
[3] Espinosa et al. (2019).
[4] Maison et al. (2015).
[5] Sotak-Peper et al. (2015).
[6] Ibagon et al. (2023).
[7] Casas et al. (2018b).

is added to the collected former food items during production of the bakery meal to meet a certain nutrient specification, which may contribute to a reduced ATTD of GE in the end-product.

The direct procedure was used to determine DE and ME in bakery meal in this experiment as has been done in the past (Rojas et al., 2013). Although this procedure may result in diets that are not adequate in all nutrients, there are no differences in DE and ME between diets using the direct procedure and the difference procedure (Oliveira et al., 2020a), and the DE and ME calculated for bakery meal in this work, therefore, are believed to be accurate. The fact that different breeds of pigs were used at the universities participating in the experiment is not believed to have impacted results because whereas differences in energy and nutrient digestibility between white breeds and indigenous breeds have been reported (Urriola and Stein, 2012), we are not aware of any differences having been demonstrated among the white breeds that are usually used in commercial production.

To the best of our knowledge, there is only one recent experiment that has reported DE and ME values in bakery meal (Rojas et al., 2013). However, the average DE and ME for the 11 sources of bakery meal used in the present experiment (3,827 and 3,678 kcal/kg DM) are in very good agreement with Rojas et al. (2013) who reported DE and ME values of 3,951 and 3,655 kcal/kg DM. In contrast, the average ME for bakery meal obtained in this experiment is somewhat greater than the ME (3,169 kcal/kg DM) reported for broiler chickens (Zhang and Adeola, 2017). It is likely that the lower value for broilers is a result of poultry having a lower digestibility of dietary fiber than pigs. Nevertheless, the ME for bakery meal obtained in this experiment and by Rojas et al. (2013) indicates that bakery meal is an ingredient with less ME than corn, but not different from the ME of wheat and sorghum and greater than barley and rye (McGhee and Stein, 2020). Likewise, the NE values calculated for bakery meal in this experiment are within the range of values reported for cereal grains (NRC, 2012). However, values for DE, ME, and NE in bakery meal obtained in this experiment are much less than the values from NRC (2012). The NRC (2012) values originated from only one observation and based on the present results, it is likely that bakery meals currently marketed in the United States have DE, ME, and NE that are considerably less than current NRC values. The reason bakery meal does not contain more DE, ME, and NE than cereal grains despite containing around 10% acid hydrolyzed ether extract may be that fiber is greater and starch is less than in cereal grains. The digestibility of intact fat is less than the digestibility of extracted fat (Kil et al., 2010; Kim et al., 2013), but it is believed that the majority of the fat used in the ingredients included in bakery meal is extracted fat, which usually has a high digestibility. However, heating of ingredients or food mixtures during food preparation may have reduced fat digestibility and thereby reduced energy in the meals as has been demonstrated for other ingredients (Oliveira et al., 2020b, 2020c).

The ME among the 11 sources of bakery meal varied from 3,450 to 4,004 kcal/kg DM. The CV of 5% to 6% for DE and ME is generally in agreement with the variability observed among different sources of soybean meal (Sotak-Peper et al., 2015; Lopez et al., 2020), canola meal (Maison et al. (2015), 00-rapeseed meal (Maison et al., 2015), wheat middlings (Casas et al., 2018b), and distillers dried grains with solubles (Espinosa et al., 2019). In these experiments, between 5 and 22 different sources of the same ingredient were used. Therefore, it appears that the blending of different product streams from the food industry and sometimes also mixing with agricultural co-products in the final bakery meals results in the producing companies being able to generate final products that meet certain minimum specifications for chemical composition and that have variability in energy values that are equivalent to what has been reported for oilseed meals and cereal grain co-products.

Overheating of some of the raw materials included in bakery meal often reduces the concentration and digestibility of Lys in bakery meal (Almeida et al., 2011; Casas et al., 2015). However, heat damage also reduces the digestibility of energy and DE and ME are reduced in overheated feed ingredients compared with non-over heated ingredients (Oliveira et al., 2020b, 2020c). One possible way to estimate heat damage in a specific feed ingredient is to calculate the ratio of Lys to crude protein (Almeida et al., 2013). However, in the present experiment, there was no correlation between the Lys to crude protein ratio and ME of bakery meal (data not shown). The reason for this lack of correlation likely is the different raw materials that are included in each meal.

Conclusions

The chemical composition of 11 sources of bakery meal was somewhat variable, but in agreement with values published previously. Average values for DE and ME in the 11 sources of bakery meal were also in agreement with published values with the exception that values were less than published by NRC (2012). However, the range of ME among sources is not greater than what has been reported for other ingredients, which indicates that companies producing bakery meal are able to generate final products that have a fairly predictable nutritional value. Overall, the average DE and ME is less than in corn, but close to values reported for wheat and sorghum.

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Conflict of Interest Statement

The authors have no conflicts of interest.

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