# Nutritional composition, gross energy concentration, and in vitro digestibility of dry matter in 46 sources of bakery meals

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**ABSTRACT:** Work was conducted to test the hypothesis that the nutritional composition of bakery meal varies depending on where in the United States the meal is produced due to different raw materials being used in the production of the meals. Forty-six samples of bakery meal were collected from feed mills located in the swine producing states in the United States. Based on the state where samples were collected, they were grouped into 5 regions: 1) AL, DE, GA, NC, PA, and VA (10 samples); 2) CO, MO, OK, and TX (10 samples); 3) IN, KY, OH, and TN (8 samples); 4) IA (11 samples); and 5) MN (7 samples). All samples were analyzed for proximate components, GE, AA, carbohydrates, and minerals, and IVDMD and in vitro energy digestibility (**IVGED**) were also determined. Results indicated that the average concentration of DM was (91.84 ± 1.29%) and there was no difference among regions. The concentration of ash in bakery meal from MN was greater ($P < 0.05$) than in meals from other regions, but for all other proximate components, no differences among sources were observed. The average concentration (DM basis) of CP (12.20 ± 2.16%), acid hydrolyzed ether extract (**AEE**, 9.38 ± 1.95%), starch (44.61 ± 5.47%), and NDF (13.77 ± 4.23%) indicated that bakery meal consists of a mixture of food ingredients originating from flour or whole cereal grains and with some high-fiber ingredients such as brans or canola coproducts also included. It also appears that oil or fats were added during production. With the exception of His, no differences among regions were observed for indispensable AA and the average concentrations (DM basis) of Lys, Met, Thr, and Trp were 0.35 ± 0.08%, 0.19 ± 0.03%, 0.38 ± 0.06%, and 0.13 ± 0.03%, respectively. The bakery meals from MN contained more ($P < 0.05$) Ca than bakery meals from other regions, indicating that limestone may have been added to bakery meal from MN to improve flowability. However, bakery meals from MN and IA contained less ($P < 0.05$) total P, phytate, and phytate-bound P than bakery meals produced in the states east of the Mississippi River. There were, however, no differences in IVDMD (79.06 ± 6.62%) or of IVGED (74.84 ± 8.20%) of bakery meals among regions. The present results indicate that variations in the chemical composition of bakery meal obtained from different regions in the United States are relatively small and likely without great impact on the nutritional value of the meals, but in vivo digestibility experiments are needed to confirm this hypothesis.

**Key words:** bakery meal, chemical composition, in vitro DM digestibility, nutrients, variability

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## INTRODUCTION

Bakery meal is a feed ingredient that is often used in diets for pigs and poultry. Bakery meal consists of a mixture of dated or unsalable bread, breakfast cereals, cookies, and other foods that cannot be used for their intended purpose (Slominski et al., 2004). By collecting, unpacking, grinding, and mixing these foods, bakery meal that may be used in the feeding of animals is produced. Although the annual production in the United States is estimated at more than 500,000 tons, only little information about the nutritional value of bakery meal is available. However, the limited data that have been published indicate that bakery meal contains 8 to 15% CP, between 5 and 10% ether extract, between 3 and 10% ash, and close to 40% starch (NRC, 2012; Rojas et al., 2013; Casas et al., 2015). There also appears to be a relatively high concentration of sucrose, glucose, maltose, and fructose in bakery meal and combined, these sugars were reported to contribute more than 15% of the DM in the ingredient (Rojas et al., 2013). The chemical composition of bakery meal reflects the composition of the different food products that were included in the meal, and the reason for the relatively large variability in composition is that different batches of bakery meal may be produced based on different combinations of food ingredients (Slominski et al., 2004). However, in general, the composition of bakery meal is closer to the composition of wheat than to that of corn reflecting that wheat flour and whole grain wheat is preferentially used in food production.

Due to the variability in raw ingredient inclusion in bakery meal, we hypothesized that bakery meal collected from certain geographical areas may have a different nutritional value than bakery meal from other areas. The objective of the present work, therefore, was to analyze the chemical composition and to determine IVDMD of bakery meal collected from a number of production facilities in the United States.

## MATERIALS AND METHODS

A total of 46 sources of bakery meal were collected from commercial feed mills and poultry and pig integrators in the United States. Ten samples were collected from a 6-state area in the eastern United States including AL, DE, GA, NC, PA, and VA. An additional 10 samples were collected from the western corn-belt including CO, MO, OK, and TX. There were 11 samples collected in IA and 8 samples from IN, KY, OH, and TN and the remaining 7 samples were all collected in MN. Approximately 1 kg of each sample was shipped to the University of Illinois (Urbana), where the chemical analyses were conducted. A subsample of each source was shipped to the University of Hawaii at Manoa where the IVDMD was determined.

### *Chemical Analyses*

All chemical analyses were performed in duplicate. The bakery meals were analyzed for DM by oven drying at 135°C for 2 h (Method 930.15; AOAC Int., 2007) and for ash (Method 942.05; AOAC Int., 2007). The concentration of N in all samples was determined using the combustion procedure (Method 990.03; AOAC Int., 2007) on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ). Aspartic acid was used as a calibration standard and CP was calculated as $N \times 6.25$. Amino acids were analyzed in all samples on a Hitachi Amino Acid Analyzer (Model L8800, Hitachi High Technologies America Inc., Pleasanton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Before analysis, samples were hydrolyzed with 6*N* HCl for 24 h at 110°C (Method 982.30 E(a); AOAC Int., 2007). Methionine and Cys were analyzed as Met sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis (Method 982.30 E(b); AOAC Int., 2007). Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C (Method 982.30 E(c); AOAC Int., 2007). Samples were analyzed for GE on an isoperibol bomb calorimeter (Model 6300, Parr Instruments, Moline, IL) using benzoic acid as the internal standard. Ingredients were also analyzed for total starch (method 76-13; AACC Int., 2000) using a modified starch assay kit (product code STA-20, Sigma, St. Louis, MO) and for glucose, fructose, maltose, sucrose, stachyose, and raffinose (Method 977.2, AOAC Int., 2007). Fructo-oligosaccharides were analyzed by refractive index high-performance liquid chromatography using a Phenomenex Rezex RHM column (Campbell et al., 1997). Insoluble dietary fiber (**IDF**) and soluble dietary fiber (**SDF**)

were determined using the Ankom$^{TDF}$ Dietary Fiber Analyzer (AOAC 991.43, AOAC Int., 2007; Ankom Technology, Macedon, NY). Total dietary fiber (**TDF**) was determined as the sum of IDF and SDF. Samples were also analyzed for NDF (Holst, 1973) and ADF (method 973.18; AOAC Int., 2007), and AEE was determined by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (method 2003.06, AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). Samples were also analyzed for Na using flame emission photometry (Method 956.01; AOAC Int., 2006), Cl using manual titration (Method 915.01, 943.01; AOAC Int., 2007), and for Ca and P by inductively coupled plasma-optical emission spectroscopy (**ICP-OES**; Method 985.01 A, B, and D; AOAC Int., 2007) after wet ash sample preparation (Method 975.03 B(b); AOAC Int., 2007). Copper, K, Mg, Mn, and Zn were measured by flame atomic absorption spectroscopy after wet ash sample preparation (Method 975.03 B(b); AOAC Int., 2007). Sulfur was measured by a gravimetric method (Method 956.01; AOAC Int., 2007). All samples were also analyzed for phytic acid (Ellis et al., 1977).

The IVDMD was determined using a 3-step procedure modified from Boisen and Fernández (1997). The procedure simulates gastric and small intestinal digestion and large intestinal fermentation. Three separate subsamples of each ingredient were used providing 3 replicates per ingredient. Samples were incubated in 125 mL Erlenmeyer flasks placed in a water bath at 39°C with constant shaking for 2 h. Pepsin from porcine gastric mucosa (Sigma P-0609; Sigma-Aldrich Corp., St. Louis, MO) was added to the flasks and the pH was maintained at 2 by adding 1 M HCl or 1 M NaOH. One mL of chloramphenicol (Sigma C-0378; Sigma-Aldrich Corp.) solution was added to prevent bacterial growth, which might take place during hydrolysis. The flask was then closed with a rubber stopper and incubated in a water bath at 39°C for 2 h under gentle agitation. After 2 h, freshly prepared pancreatin solution (Sigma P-1750; Sigma-Aldrich) was added to each flask and the pH was adjusted to 6.8 by adding 1 M HCl or 1 M NaOH. The hydrolysis was continued for 4 h under the same conditions. These steps represented the digestion processes in the stomach and the small intestine, respectively. At the end of the of incubation, 20 mL of a 0.2 M EDTA solution was added to the flask, and the pH was adjusted to 4.8 with a 30% acetic acid solution. Then 1 mL of Viscozyme (a multienzyme complex obtained from *Aspergillus aculeatus* containing cellulase, β-glucanase, arabinase, xylanase, mannanase, and pectinase; Novozymes, Bagsværd, Denmark) was added and the flask was incubated at 39°C for 18 h.

The undigested residue was then collected in a filtration unit using a porcelain filtration funnel lined with pre-weighed filter paper (Whatman no. 54; Whatman Inc., Florham Park, NJ). All the material was transferred with double-distilled water to the funnel. The residue, along with the filter paper, was dried overnight at 80°C and weighed the next day.

### *Calculations and Data Analyses*

The concentration of OM was calculated by subtracting analyzed ash from DM and hemicellulose was calculated as the difference between NDF and ADF. Phytate-bound P was calculated as 28.2% of analyzed phytic acid (Tran and Sauvant, 2004), and non-phytate P was calculated as the difference between total P and phytate-bound P.

Data were analyzed by ANOVA using the Mixed procedure in SAS (SAS Stat Inst., Cary, NC). Means for each region were calculated using the least significant means procedure in SAS, and if differences among regions were observed, means were separated using the PDIFF option in SAS. An overall average for all 46 sources of bakery meal was also calculated. Each individual sample of bakery meal was the experimental unit. An alpha value of 0.05 was used to assess significance among geographical areas and if the *P* value was between 0.05 and 0.10, the difference was considered a tendency.

## RESULTS AND DISCUSSION

Accurate formulation of diets for pigs depends on having access to accurate values for the nutritional composition of feed ingredients. However, for bakery meal, the published information on nutritional composition is very limited (NRC, 2012). In the past, manuscripts detailing the chemical composition of corn, soybean meal, wheat middlings, and distillers dried grains with solubles have been published (Cromwell et al., 1999, 2000; Spiehs et al., 2002), and recently, a manuscript with information about the concentration of minerals in feed ingredients produced in China was published (Huang et al., 2017). The present work was undertaken to provide a more robust database for bakery meal that may be used in diet formulations.

The 46 sources of bakery meal analyzed in this work were collected from feed mills or pig or poultry integrators from most pig-producing states

in the United States. It is, therefore, believed that the present data provide representative information about the composition of bakery meal currently marketed in the United States. However, whereas the location of the feed mills where the bakery meals were collected is known, it is acknowledged that it is possible that some of the meals were produced in other states and subsequently shipped into the state where they were collected. Thus, the present data do not necessarily provide information about production of bakery meal in the different states but only about the states where it was used.

The DM in bakery meals, regardless of where collected, was close to 92% indicating that bakery meal has a greater concentration of DM than most other feed ingredients commonly used in diets for pigs (Table 1). The standardized ileal digestibility of CP and AA in 2 sources of bakery meal was determined by Almeida et al. (2011) and by Casas et al. (2015), and results of both experiments indicated that bakery meal may sometimes be heat damaged with a relatively low digestibility of Lys as a consequence. The high concentration of DM in the bakery meals used in this research indicates that the bakery meal or the food ingredients that were used to produce the bakery meal have gone through more drying than what is usual for agricultural feed ingredients and this may be the reason for the reduced digestibility of Lys that has been reported.

Concentrations of ash were greater ($P < 0.05$) in bakery meal from MN than in bakery meal from the other 4 regions, but no differences among the other 4 geographical areas were observed. However, the concentration of ash (between 4.28 and 5.78%, DM basis) in all sources of bakery meal was much greater than what is usually present in cereal grains (NRC, 2012). The reason for this observation may be that NaCl and other minerals often are added to human foods, which results in a relatively high concentration of ash in the raw materials used in the production of bakery meal. Data for concentrations of DE and ME indicate that bakery meal contains less ME than corn, which may be a result of

**Table 1.** Analyzed chemical composition of different bakery meals, DM basis

| | Region[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Item | ADGNPV | CMOT | IA | IKOT | MN | SEM | *P* value | Average[3] |
| *N* | 10 | 10 | 11 | 8 | 7 | — | — | — |
| GE, kcal/kg | 4,659 | 4,684 | 4,617 | 4,702 | 4,548 | 41.28 | 0.13 | 4,645 ± 129 |
| DM, % | 92.05 | 92.08 | 91.83 | 91.95 | 91.13 | 0.44 | 0.62 | 91.84 ± 1.29 |
| Ash, % | 4.28$^{b}$ | 4.69$^{b}$ | 4.46$^{b}$ | 4.28$^{b}$ | 5.78$^{a}$ | 0.33 | <0.05 | 4.64 ± 1.09 |
| OM, % | 87.76$^{y}$ | 87.39$^{y}$ | 87.37$^{y}$ | 87.67$^{y}$ | 85.35$^{x}$ | 0.62 | 0.09 | 87.20 ± 1.94 |
| CP, % | 12.42$^{y}$ | 12.25$^{y}$ | 11.59$^{yx}$ | 13.84$^{y}$ | 10.87$^{x}$ | 0.68 | 0.07 | 12.20 ± 2.16 |
| AEE, % | 9.57 | 10.16 | 9.43 | 8.79 | 8.95 | 0.66 | 0.61 | 9.38 ± 1.95 |
| Starch, % | 45.09 | 42.09 | 46.97 | 44.04 | 44.43 | 1.81 | 0.37 | 44.61 ± 5.47 |
| IDF, % | 19.30 | 18.34 | 18.13 | 16.83 | 17.03 | 1.47 | 0.74 | 18.09 ± 3.93 |
| SDF, % | 2.31 | 1.39 | 1.67 | 1.39 | 0.61 | 0.62 | 0.47 | 1.57 ± 1.71 |
| TDF, % | 21.60 | 19.63 | 19.78 | 18.19 | 17.53 | 1.54 | 0.40 | 19.59 ± 4.24 |
| ADF, % | 6.31 | 6.05 | 6.09 | 5.70 | 6.89 | 0.57 | 0.74 | 6.18 ± 1.68 |
| NDF, % | 13.16 | 13.89 | 14.25 | 12.59 | 15.09 | 1.45 | 0.81 | 13.77 ± 4.23 |
| Hemicellulose, % | 6.86 | 7.84 | 8.15 | 6.89 | 8.20 | 1.14 | 0.85 | 7.59 ± 3.32 |
| Carbohydrates, % | | | | | | | | |
| Fructose | 1.38 | 1.89 | 1.86 | 1.55 | 1.97 | 0.31 | 0.61 | 1.72 ± 0.91 |
| Glucose | 2.10 | 2.84 | 2.55 | 2.37 | 3.22 | 0.48 | 0.58 | 2.58 ± 1.44 |
| Sucrose | 3.89 | 3.24 | 3.29 | 3.25 | 3.70 | 0.63 | 0.91 | 3.47 ± 1.81 |
| Maltose | 3.17 | 2.83 | 3.31 | 3.61 | 3.33 | 0.32 | 0.55 | 3.23 ± 0.96 |
| Raffinose | 0.32 | 0.26 | 0.26 | 0.35 | 0.22 | 0.045 | 0.33 | 0.28 ± 0.14 |
| Stachyose | 0.024 | 0.018 | 0.017 | 0.001 | 0.014 | 0.007 | 0.31 | 0.02 ± 0.02 |
| FOS[2] + ketose | 2.00 | 2.06 | 1.96 | 2.30 | 1.98 | 0.163 | 0.62 | 2.05 ± 0.48 |
| FOS[2] | 0.73 | 0.73 | 0.51 | 1.03 | 0.75 | 0.264 | 0.73 | 0.74 ± 0.62 |

IDF = insoluble dietary fiber; SDF = soluble dietary fiber; TDF = total dietary fiber.

[a,b]Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]A total of 46 bakery meal samples were analyzed based on 5 regions. ADGNPV includes AL, DE, GA, NC, PA, and VA; CMOT includes CO, MO, OK, and TX; and IKOT includes IN, KY, OH, and TN.

[2]Fructooligosaccharides.

[3]Average and standard deviation values for all 46 bakery meal samples.

the high concentration of ash in the product (Rojas et al., 2013).

Concentrations of OM and CP tended ($P < 0.10$) to be less in bakery meal from MN than in bakery meal from the other regions. However, despite the increased ash concentration and the tendency for the reduced OM and CP, the GE in the bakery meal from MN was not less than that of bakery meal produced in other areas. The concentration of AEE was on average 9.43% (DM basis) and not different among locations. However, the relatively high concentration of AEE indicates that fat or oil was added to the foods that were used in the production of bakery meal. The concentrations of ADF and NDF (6.18 and 13.77%, DM basis) as well as the concentrations of TDF (19.59%, DM basis) indicates that some of the food ingredients used in the production of bakery meal contain whole grains and likely some high-fiber ingredients such as wheat bran or oat fiber as well. However, the concentration of starch (44.61%, DM basis) indicates that flour and cereal grains were the main components in the food ingredients used in the production of bakery meal.

The average concentration of sucrose in the bakery meals was 3.47% (DM basis) indicating that sugar may have been added to the ingredients included in the bakery meal. Likewise, average concentrations of fructose, glucose, and maltose were 1.72, 2.58, and 3.23% (DM basis), respectively, which may be a result of dextrose or other refined sugars being added to the food. However, the very low concentration of stachyose indicates that appreciable amounts of soy flour are not added to foods included in the production of bakery meal.

The concentration of His and Gly in bakery meal from MN and IA was less ($P < 0.05$) than in bakery meal from IN, KY, OH, and TN and the concentration of His and Gly in bakery meal from MN was also less ($P < 0.05$) than in bakery meal from AL, DE, GA, NC, PA, and VA (Table 2). There was also a tendency ($P < 0.10$) for the concentration of Arg, Cys, Tyr, all dispensable AA, and all AA to be less in bakery meal from MN than in

**Table 2.** Concentration of AA in bakery meal, DM basis

| | Region[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Item | ADGNPV | CMOT | IA | IKOT | MN | SEM | *P* value | Average[2] |
| *N* | 10 | 10 | 11 | 8 | 7 | — | — | — |
| Indispensable AA, % | | | | | | | | |
| Arg | 0.62$^{xy}$ | 0.56$^{xy}$ | 0.51$^{xy}$ | 0.63$^{y}$ | 0.48$^{x}$ | 0.041 | 0.06 | 0.56 ± 0.13 |
| His | 0.28$^{ab}$ | 0.27$^{abc}$ | 0.25$^{bc}$ | 0.30$^{a}$ | 0.23$^{c}$ | 0.015 | <0.05 | 0.26 ± 0.05 |
| Ile | 0.44 | 0.44 | 0.41 | 0.48 | 0.39 | 0.023 | 0.14 | 0.43 ± 0.07 |
| Leu | 0.90 | 0.93 | 0.87 | 0.95 | 0.82 | 0.047 | 0.35 | 0.89 ± 0.14 |
| Lys | 0.37 | 0.38 | 0.32 | 0.37 | 0.31 | 0.026 | 0.26 | 0.35 ± 0.08 |
| Met | 0.19 | 0.20 | 0.18 | 0.21 | 0.17 | 0.011 | 0.30 | 0.19 ± 0.03 |
| Phe | 0.56 | 0.56 | 0.54 | 0.62 | 0.51 | 0.032 | 0.24 | 0.56 ± 0.10 |
| Thr | 0.38 | 0.39 | 0.36 | 0.41 | 0.34 | 0.021 | 0.23 | 0.38 ± 0.06 |
| Trp | 0.14 | 0.14 | 0.12 | 0.15 | 0.12 | 0.008 | 0.11 | 0.13 ± 0.03 |
| Val | 0.56 | 0.56 | 0.52 | 0.61 | 0.50 | 0.030 | 0.17 | 0.55 ± 0.09 |
| Total | 4.44 | 4.43 | 4.09 | 4.72 | 3.87 | 0.23 | 0.15 | 4.32 ± 0.73 |
| Dispensable AA, % | | | | | | | | |
| Ala | 0.53 | 0.54 | 0.50 | 0.56 | 0.47 | 0.033 | 0.43 | 0.52 ± 0.10 |
| Asp | 0.79 | 0.75 | 0.69 | 0.79 | 0.67 | 0.048 | 0.34 | 0.74 ± 0.14 |
| Cys | 0.23$^{xy}$ | 0.23$^{xy}$ | 0.22$^{xy}$ | 0.26$^{y}$ | 0.20$^{x}$ | 0.012 | 0.09 | 0.23 ± 0.04 |
| Glu | 2.74 | 2.69 | 2.61 | 3.19 | 2.46 | 0.20 | 0.18 | 2.74 ± 0.62 |
| Gly | 0.54$^{ab}$ | 0.50$^{abc}$ | 0.46$^{bc}$ | 0.59$^{a}$ | 0.43$^{c}$ | 0.035 | <0.05 | 0.51 ± 0.11 |
| Pro | 0.94 | 0.97 | 0.92 | 1.12 | 0.87 | 0.067 | 0.16 | 0.96 ± 0.21 |
| Ser | 0.52 | 0.51 | 0.49 | 0.55 | 0.45 | 0.026 | 0.20 | 0.50 ± 0.08 |
| Tyr | 0.33$^{xy}$ | 0.34$^{xy}$ | 0.29$^{xy}$ | 0.35$^{y}$ | 0.28$^{x}$ | 0.019 | 0.07 | 0.32 ± 0.06 |
| Total | 6.62$^{xy}$ | 6.53$^{xy}$ | 6.20$^{xy}$ | 7.40$^{y}$ | 5.84$^{x}$ | 0.37 | 0.09 | 6.51 ± 1.17 |
| Total AA, % | 11.05$^{xy}$ | 10.97$^{xy}$ | 10.29$^{xy}$ | 12.12$^{y}$ | 9.71$^{x}$ | 0.58 | 0.09 | 10.83 ± 1.83 |

$^{a-c}$Means within a row lacking a common superscript letter differ ($P < 0.05$).

$^{xy}$Means within a row lacking a common superscript letter tended to differ ($P < 0.10$).

[1]A total of 46 bakery meal samples were analyzed based on 5 regions. ADGNPV includes AL, DE, GA, NC, PA, and VA; CMOT includes CO, MO, OK, and TX; and IKOT includes IN, KY, OH, and TN.

[2]Average and standard deviation values for all 46 bakery meal samples.

bakery meal from IN, KY, OH, and TN. It is likely that the tendency for reduced CP in bakery meal from MN is the reason for the reduced concentrations of His and Gly and the tendencies for reduced concentrations of a few other AA in the bakery meal from MN. The average concentration of Lys (0.35%, DM basis) is within the range of previously published values (Almeida et al., 2011; NRC, 2012; Rojas et al., 2013; Casas et al., 2015) and relatively close to the value observed in many cereal grains.

The concentration of Ca was much greater ($P < 0.05$) in bakery meals from MN compared with bakery meals from all other locations (Table 3). Concentrations of Ca that were observed in this study were for the most part greater than previously reported values (Almeida et al., 2011; NRC, 2012; Rojas et al., 2013; Casas et al., 2015). There is very little Ca in cereal grains and in general, plant ingredients do not contribute much Ca to diets (Stein et al., 2016). It is, therefore, likely that the majority of the Ca in the bakery meal originates from calcium carbonate added to the foods during preparation to fortify foods with Ca. It is, however, also possible that specifically for the bakery meal from MN, limestone was added after production to improve flowability.

The concentration of total P, phytic acid, and phytate-bound P was less ($P < 0.05$) in bakery meal from MN and IA than in bakery meal from AL, DE, GA, NC, PA, and VA and from IN, KY, OH, and TN, but there were no differences in concentrations of K, Mg, and S among regions. However, regardless of location, the P in the bakery meal observed in this study was within the range of previously published values (NRC, 2012; Rojas et al., 2013; Casas et al., 2015). The greater concentrations of P and phytic acid in bakery meal from some states compared with others indicate that there may have been some high-P and high phytate ingredients such as bran and possibly also canola coproducts included in bakery meal from these locations. In general, the concentration of P in bakery meal from all states except MN was greater than expected if only grain flours were included in the meals further indicating that ingredients with greater P concentration than cereal grains were included in the foods that made up the bakery meals. The standardized total-tract digestibility of P is greater in bakery meal than in corn (Rojas et al., 2013), which is consistent with the fact that the digestibility of P is greater in wheat than in corn (NRC, 2012).

**Table 3.** Concentrations of macro minerals and micro minerals in different bakery meals, DM basis

| | Region[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Item | ADGNPV | CMOT | IA | IKOT | MN | SEM | *P* value | Average[3] |
| *N* | 10 | 10 | 11 | 8 | 7 | — | — | — |
| Macro minerals, % | | | | | | | | |
| Ca | 0.19[b] | 0.29[b] | 0.19[b] | 0.20[b] | 0.56[a] | 0.076 | <0.05 | 0.27 ± 0.25 |
| P | 0.40[a] | 0.37[ab] | 0.32[b] | 0.44[a] | 0.29[b] | 0.028 | <0.01 | 0.36 ± 0.10 |
| Phytic acid | 0.86[a] | 0.68[ab] | 0.59[b] | 0.94[a] | 0.55[b] | 0.092 | <0.05 | 0.72 ± 0.30 |
| Phytate P[2] | 0.24[a] | 0.19[ab] | 0.17[b] | 0.27[a] | 0.15[b] | 0.026 | <0.05 | 0.20 ± 0.09 |
| Non-phytate P[2] | 0.16 | 0.18 | 0.15 | 0.17 | 0.14 | 0.013 | 0.19 | 0.16 ± 0.04 |
| Na | 0.54 | 0.59 | 0.54 | 0.59 | 0.50 | 0.059 | 0.82 | 0.55 ± 0.17 |
| Cl | 0.74 | 0.82 | 0.75 | 0.84 | 0.70 | 0.084 | 0.78 | 0.77 ± 0.25 |
| K | 0.48 | 0.46 | 0.42 | 0.51 | 0.39 | 0.039 | 0.30 | 0.45 ± 0.12 |
| Mg | 0.15 | 0.14 | 0.13 | 0.16 | 0.13 | 0.015 | 0.53 | 0.14 ± 0.05 |
| S | 0.19 | 0.20 | 0.20 | 0.20 | 0.19 | 0.015 | 0.91 | 0.20 ± 0.04 |
| Micro minerals, mg/kg | | | | | | | | |
| Cu | 6.07 | 6.41 | 5.27 | 7.28 | 5.23 | 0.66 | 0.20 | 6.04 ± 2.04 |
| Fe | 219[c] | 334[bc] | 390[ab] | 191[c] | 554[a] | 61.0 | <0.01 | 331 ± 213 |
| Cr | 5.74 | 4.88 | 6.87 | 6.73 | 8.93 | 2.03 | 0.68 | 6.57 ± 4.94 |
| Mn | 39.16[a] | 32.12[ab] | 28.26[b] | 38.63[a] | 31.11[ab] | 2.89 | <0.05 | 33.71 ± 0.15 |
| Mo | 0.54 | 4.92 | 12.51 | 0.48 | 2.56 | 5.67 | 0.49 | 4.65 ± 16.94 |
| Zn | 41.72 | 50.03 | 43.00 | 44.45 | 51.97 | 5.36 | 0.61 | 45.87 ± 0.15 |

[a–c]Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]A total of 46 bakery meal samples were analyzed based on 5 regions. ADGNPV includes AL, DE, GA, NC, PA, and VA; CMOT includes CO, MO, OK, and TX; and IKOT includes IN, KY, OH, and TN.

[2]Phytate P was calculated as 28.2% of analyzed phytic acid (Sauvant et al., 2004); non-phytate P was calculated by subtracting phytate P from total P.

[3]Average and standard deviation values for all 46 bakery meal samples.

**Table 4.** IVDMD and in vitro energy digestibility (IVGED) in different bakery meals

| | Region[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Item | ADGNPV | CMOT | IA | IKOT | MN | SEM | *P* value | Average[2] |
| *N* | 10 | 10 | 11 | 8 | 7 | — | — | — |
| IVDMD, % | 77.71 | 78.67 | 81.33 | 77.02 | 80.05 | 2.29 | 0.64 | 79.06 ± 6.62 |
| IVGED, % | 71.84 | 78.53 | 77.26 | 70.24 | 75.45 | 2.70 | 0.16 | 74.84 ± 8.20 |

[1]A total of 46 bakery meal samples were analyzed based on 5 regions. ADGNPV includes AL, DE, GA, NC, PA, and VA; CMOT includes CO, MO, OK, and TX; and IKOT includes IN, KY, OH, and TN. Three replicate subsamples of each bakery meal were analyzed.

[2]Average and standard deviation values for all 46 bakery meal samples.

The average concentrations of Na and Cl were 0.55 and 0.77% (DM basis), respectively, and no differences among regions were observed. Thus, the concentration of Na and Cl is much greater in bakery meal than in any of the plant-based feed ingredients that may be used in diets for pigs (NRC, 2012). It is, therefore, very likely that most of the foods included in bakery meal are fortified with NaCl and possibly other sources of minerals to increase the concentration of Na. Assuming that the plant-based ingredients that were used in the production of the foods in the bakery meal have negligible concentrations of Na, and assuming that NaCl contains 39.5% Na (NRC, 2012), it is concluded that approximately 1.25% NaCl (as-is basis) was included in the foods used to produce the bakery meal. In contrast to Na and Cl, concentrations of K and Mg were close to what is expected in cereal grains and it appears, therefore, that these minerals were not added to the foods used in the bakery meals.

The concentration of Fe was greater ($P < 0.05$) in bakery meal from MN than in bakery meal form all other regions except IA and bakery meal from IA contained more ($P < 0.05$) Fe than bakery meal from AL, DE, GA, NC, PA, and VA or from IN, KY, OH, and TN. These observations indicate that that the foods included in the bakery meal from MN and IA were fortified with Fe. Bakery meal from AL, DE, GA, NC, PA, and VA or from IN, KY, OH, and TN contained more ($P < 0.05$) Mn than bakery meal from IA, but for Cu, Cr, Mo, and Zn, no differences among locations were observed.

Differences in IVDMD among sources of bakery meal were not observed (Table 4). In general, values for IVDMD obtained in this study are less than what is generally observed for cereal grains and closer to that observed for some high-fiber cereal grain coproducts (Jaworski et al., 2015; Navarro et al., 2018). This observation is supported by the concentrations of ADF and NDF, which are also greater than in cereal grains and this further indicates that some high-fiber ingredients likely were included in the sources of food that were used in the production of the bakery meals.

## CONCLUSIONS

The chemical composition of bakery meal indicates that although the majority of the ingredients likely originate from flours and possibly whole grain cereal foods, high-fiber ingredients likely also are included in the product mix used to produce the foods that generate bakery meal. Thus, bakery meal contains more than 40% starch, but concentrations of ADF, NDF, and phytate-bound P are greater than in cereal grains. The concentration of AEE is 8 to 10% indicating that fats or oils are also added to the food mix. Differences among geographical regions in the United States in the chemical composition of bakery meals appear to be relatively small and only were observed for a few nutrients. This observation gives confidence that average values may be used to predict concentrations of nutrients in bakery meals. However, it is acknowledged that to provide additional information about the nutritional value of bakery meals, in vivo values for the digestibility of energy, AA, and minerals are also needed and future work should focus on generating such values.

## LITERATURE CITED

AACC International. 2000. Approved Methods of the American Association of Cereal Chemists. 10th ed. AACC Int., St, Paul, MN.

Almeida, F. N., G. I. Petersen, and H. H. Stein. 2011. Digestibility of amino acids in corn, corn coproducts, and bakery meal fed to growing pigs. J. Anim. Sci. 89:4109–4115. doi:10.2527/jas.2011-4143.

AOAC. 2006. In W. Howitz, editor. Official methods of analysis. 18th ed. Rev. 2. Assoc. Off. Anal. Chem., Arlington, VA.

AOAC Int. 2007. In W. Howitz and G. W. Latimer Jr, editors. Official methods of analysis. 18th ed. Rev. 2. AOAC Int., Gaithersburg, MD.

Boisen, S., and J. A. Fernández. 1997. Prediction of the total tract digestibility of energy in feedstuffs and pig diets by in vitro analyses. Anim. Feed Sci. Technol. 68:277–286. doi:10.1016/S0377-8401(97)00058-8

Campbell, J. M., L. L. Bauer, G. C. Fahey, Jr., A. J. C. L. Hogarth, B. W. Wolf, and D. E. Hunter. 1997. Selected fructooligosaccharide (1-kestose, nystose, and $1^F$-β fructofuranosylnystose) composition of foods and feeds. J. Agric. Food Chem. 45:3076–3082. doi:10.1021/jf970087g

Casas, G. A., J. A. S. Almeida, and H. H. Stein. 2015. Amino acid digestibility in rice co-products fed to growing pigs. Anim. Feed. Sci. Technol. 207:150–158. Doi:org/10.1016/j.anifeedsci.2015.05.024

Cromwell, G. L., C. C. Calvert, T. R. Cline, J. D. Crenshaw, T. D. Crenshaw, R. A. Easter, R. C. Ewan, C. R. Hamilton, G. M. Hill, A. J. Lewis, et al. 1999. Variability among sources and laboratories in nutrient analyses of corn and soybean meal. NCR-42 committee on swine nutrition. North central regional-42. J. Anim. Sci. 77:3262–3273.

Cromwell, G. L., T. R. Cline, J. D. Crenshaw, T. D. Crenshaw, R. A. Easter, R. C. Ewan, C. R. Hamilton, G. M. Hill, A. J. Lewis, D. C. Mahan, et al. 2000. Variability among sources and laboratories in analyses of wheat middlings. NCR-42 committee on swine nutrition. J. Anim. Sci. 78:2652–2658. doi:10.2527/2000.78102652x

Ellis, R., E. R. Morris, and C. Philpot. 1977. Quantitative determination of phytate in the presence of high inorganic phosphate. Anal. Biochem. 77:536–539. doi:10.1016/0003-2697(77)90269-X

Holst, D. O. 1973. Holst filtration apparatus for Van Soest detergent fiber analysis. J. AOAC. 56:1352–1356.

Huang, C. F., H. H. Stein, L. Y. Zhang, D. Li, and C. H. Lai. 2017. Concentration of minerals in pig feed ingredients commonly used in China. Transl. Anim. Sci. 1:168–178.

Jaworski, N. W., H. N. Lærke, K. E. Bach Knudsen, and H. H. Stein. 2015. Carbohydrate composition and in vitro digestibility of dry matter and nonstarch polysaccharides in corn, sorghum, and wheat and coproducts from these grains. J. Anim. Sci. 93:1103–1113. doi:10.2527/jas.2014-8147.

Navarro, D. M. D. L., E. M. A. M. Bruininx, L. de Jong, and H. H. Stein. 2018. Analysis for low-molecular weight carbohydrates are needed to account for all energy contributing nutrients in some feed ingredients, but physical characteristics do not predict in vitro digestibility of dry matter. J. Anim. Sci. 96:532–544. doi:10.1093/jas/sky010

NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Natl. Acad. Press, Washington, DC. doi:10.17226/13298

Rojas, O. J., Y. Liu, and H. H. Stein. 2013. Phosphorus digestibility and concentration of digestible and metabolizable energy in corn, corn coproducts, and bakery meal fed to growing pigs. J. Anim. Sci. 91:5326–5335. doi:10.2527/jas.2013-6324.

Sanderson, P. 1986. A new method of analysis of feeding stuffs for the determination of crude oils and fats. In: W. Haresign and D. J. A. Cole, editors, Recent Advances in Animal Nutrition. Butterworths, London, U.K. p. 77–81.

Sauvant, D., J.-M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials: Pig, poultry, sheep, goats, rabbits, horses, fish. 2nd ed. Wageningen Academic Publishers, Wageningen, The Netherlands. doi:10.3920/978-90-8686-668-7

Slominski, B. A., D. Boros, L. D. Campbell, W. Guenter, and O. Jones. 2004. Wheat by-products in poultry nutrition. Part I. Chemical and nutritive composition of wheat screenings, bakery by-products and wheat mill run. Can. J. Anim. Sci. 84:421–428.

Spiehs, M. J., M. H. Whitney, and G. C. Shurson. 2002. Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 80:2639–2645. Doi:10.1093/ansci/80.10.2639

Stein, H. H., L. A. Merriman, and J. C. Gonzalez-Vega. 2016. Establishing a digestible calcium requirement for pigs. In: C. L. Walk, I. Kuhn, H. H. Stein, M. T. Kidd, and M. Rodehutscord, editor. Phytate destruction. Consequences for precision animal nutrition. Wageningen Academic Publishers, Wageningen, The Netherlands. P. 207–216. doi:10.3920/978-90-8686-836-0_13

Tran, G., and D. Sauvant. 2004. Chemical data and nutritional value. In: D. Sauvant, J.-M. Perez, and G. Tran, editors. Tables of composition and nutrition value of feed materials: Pig, poultry, sheep, goats, rabbits, horses, fish. 2nd ed. Wageningen Academic Publishers, Wageningen, The Netherlands. p. 17–24. doi:10.3920/978-90-8686-668-7