Nutrient composition and digestibility of energy and nutrients in wheat middlings and red dog fed to growing pigs[1]

G. A. Casas[†,‡], D. A. Rodriguez[†], and H. H. Stein[†,‖,2]

[†]Department of Animal Sciences, University of Illinois, Urbana 61801; [‡]Universidad Nacional de Colombia, Bogotá, Colombia, Departamento de Producción Animal, Facultad de Medicina Veterinaria y de Zootecnia; [‖]Division of Nutritional Sciences, University of Illinois, Urbana 61801

ABSTRACT: This experiment was designed to determine nutrient composition and apparent total tract digestibility (**ATTD**) of GE, DM, OM, and NDF and the concentration of DE and ME in 10 sources of wheat middlings and in 1 source of red dog that were obtained from different flour mills in the United States. Twelve growing pigs (initial BW: 31.0 ± 1.0 kg) were randomly allotted to a 12 × 8 Youden square design with 12 dietary treatments and eight 14 d periods. Pigs were individually housed in metabolism crates for total collection of feces and urine. A basal diet based on corn and soybean meal, and 11 diets containing corn, soybean meal, and 39.4% of one of the 10 sources of wheat middlings or of red dog were formulated. The ATTD of GE, DM, OM, and NDF in all diets was calculated using the direct procedure, and the ATTD of GE, DM, OM, and NDF in each source of wheat middlings or red dog was calculated by difference. Values for DE and ME were calculated as well. The average concentration of CP was 17.67% in wheat midlings and 17.0% in red dog, and the concentration of acid hydrolyzed ether extract (**AEE**) and total dietary fiber (**TDF**) was 2.44 and 13.90% in red dog, but 4.07 and 36.45% in wheat middlings. Red dog also contained more starch (42.98%) than wheat middlings (20.28%). Red dog had greater bulk density (498.5 g/L) and smaller particle size (146 µm) compared with wheat middlings (315.1 g/L and 783 µm). The average ATTD of GE, DM, OM, and NDF in wheat middlings (67.2%, 71.2%, 72.9%, and 53.0%, respectively) was less ($P < 0.05$) than in red dog (79.35%, 82.9%, 86.6%, and 58.7%, respectively). The average concentrations of DE and ME in wheat middlings were 2,990 and 2,893 kcal/kg DM, and these values were less ($P < 0.05$) than the DE and ME in red dog (3,408 and 3,292 kcal/kg DM). In conclusion, wheat middlings contains more fiber and less starch than red dog and the ATTD of GE and nutrients is greater in red dog than in wheat middlings. As a consequence, concentrations of DE and ME are greater in red dog than in wheat middlings.

Key words: digestibility, energy, fiber, growing pigs, red dog, wheat middlings

J. Anim. Sci. 2018.96:215–224
doi: 10.1093/jas/skx010

INTRODUCTION

Cereal coproducts are important sources of energy for pigs and inclusion of cereal coproducts in diets for pigs has increased in the last decade, but a major concern of using cereal coproducts in diets for pigs is batch-to-batch variation in nutrient composition (Zijlstra and Beltranena, 2013). These differences are a consequence of certain fractions of the grain kernel being concentrated in the coproduct, and differences in processing procedures also contribute to differences among coproducts. In wheat milling, approximately 25% of the grain remains as coproducts, which are available for

[1]Funding for this research from the National Pork Board, Des Moines, IA, is much appreciated.

[2]Corresponding author: hstein@illinois.edu

Received October 9, 2017.
Accepted February 2, 2018.

animal feeding (Blasi et al., 1998; Bond and Liefert, 2017), and among wheat coproducts, wheat middlings is the most common ingredient used in animal feeding (Blasi et al., 1998). Red dog, which is a mix of fractions of fiber and endosperm from wheat grain, is also produced in some wheat mills (Blasi et al., 1998). The composition and nutritional value of wheat middlings and red dog depend on the proportion of bran, germ, and flour that is included in the final product, the characteristics of the original wheat grain, and the milling process (Cromwell et al., 2000; Huang et al., 2012; Rosenfelder et al., 2013). Chemical composition and energy values of wheat coproducts from some countries have been determined, (Nyachoti et al., 2005; Huang et al., 2012), but there is limited information about the quality of wheat coproducts from the United States. Wheat and wheat coproducts have greater concentration of nonstarch polysaccharides (**NSP**) compared with other grains and coproducts commonly used in diets for pigs, which may negatively affect nutrient and energy digestibility (Bach Knudsen, 1997; Slominski et al., 2004; Nortey et al., 2008; Jaworski et al., 2015). Therefore, the objective of this experiment was to determine the composition and the apparent total tract digestibility (**ATTD**) of GE, DM, OM, and NDF and the concentration of DE and ME in 10 sources of wheat middlings and 1 source of red dog that were obtained from different flour mills in the United States.

MATERIALS AND METHODS

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. The red dog that was used in the experiment was produced in IA, and the 10 sources of wheat middlings were produced in CO, IA, IL, KS, MI, MN, OH, and PA (Table 1). Digestibility of CP and AA in the same batches of these ingredients was determined in a separate experiment (Casas and Stein, 2017).

Animals and Housing

Twelve growing pigs that were the offspring of Line 359 boars mated to Camborough sows (Pig Improvement Company, Hendersonville, TN) with an average initial BW of 31.0 ± 1.0 kg were randomly allotted to a 12 × 8 Youden square design with 12 dietary treatments and eight 14 d periods. Pigs were individually housed in metabolism crates that were equipped with a feeder, a nipple drinker, a fully slatted floor, a screen floor, and a urine tray, which allowed for total collection of feces and urine.

Diets and Feeding

A basal diet based corn and soybean meal was formulated. Ten additional diets containing corn, soybean meal, and one of the 10 sources of wheat middlings and one diet containing corn, soybean meal, and red dog were also formulated (Tables 2 and 3). Each source of wheat middlings or red dog was included at 39.40% in the diets. Wheat middlings or red dog and corn and soybean meal were the only sources of energy in the diets, and the ratio between corn and soybean meal was constant among all diets. Vitamins and minerals were included in concentrations that exceeded the requirements for growing pigs (NRC, 2012). Feed was provided at a daily level of 3 times the maintenance energy requirement (i.e., 197 kcal/kg $BW^{0.60}$; NRC, 2012), and pigs were fed equal amounts of feed twice daily at 0700 and 1600 h. Water was available at all times throughout the experiment.

Sample Collection

Pig weights were recorded at the beginning of the experiment and at the end of each period. The initial 7 d of each period was considered the adaptation period to the diet. Fecal markers were fed in the morning meals on day 8 (chromic oxide) and day 13 (ferric oxide), and fecal collection was initiated when chromic oxide appeared in the feces and ceased when ferric oxide appeared (Adeola, 2001). Feces were collected twice daily and stored at −20 °C as soon as collected. Urine collection started on day 8 at 1700 h and ceased on day 13 at 1700 h. Urine was collected in buckets placed under the metabolism crates that contained a preservative of 50 mL of 6 *N* HCl. Buckets were emptied daily, weights of the collected urine were recorded, and 20% of the collected urine was stored at −20 °C. At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet and subsamples were collected and lyophilized (Kim et al., 2009). Fecal samples were dried at 65 °C in a forced air oven and ground through a 1 mm screen in a Willey mill (Model 4; Thomas Scientific, Swedesboro, NJ).

Chemical Analyses

Ingredients, diets, fecal samples, and urines samples were analyzed in duplicate for GE using an isoperibol bomb calorimeter (Model 6300, Parr Instruments, Moline, IL) with benzoic acid as the standard for calibration. Ingredients, diets, and fecal samples were analyzed in duplicate for DM

Table 1. Analyzed composition (as-fed basis) of corn, soybean meal, red dog, and 10 sources of wheat middlings

				Wheat middlings, source											
Item	Corn	Soybean meal	Red dog	1	2	3	4	5	6	7	8	9	10	Mean[1]	SD[1]
GE, kcal/kg	3,819	4,207	3,801	3,838	3,871	4,033	3,900	4,046	3,996	4,029	4,012	4,045	4,015	3,979	77.97
DM	86.25	88.99	89.47	86.51	87.80	89.44	89.98	89.20	89.13	88.74	88.01	89.55	89.32	88.80	1.04
CP	6.80	48.05	17.00	17.75	18.39	17.21	18.83	18.13	17.00	17.10	17.98	17.30	17.01	17.67	0.64
AEE[2]	3.65	2.44	2.50	2.33	4.60	4.02	3.31	4.98	3.96	4.04	4.25	4.50	4.71	4.07	0.77
ADF	2.31	5.12	3.37	11.01	9.99	9.44	10.77	12.22	10.74	10.24	10.27	11.52	11.87	10.81	0.87
NDF	9.01	8.30	11.81	34.35	33.08	33.72	35.61	40.28	34.30	33.62	34.04	37.71	38.4	35.51	2.44
TDF[2]	3.40	18.5	13.90	34.40	34.10	33.20	36.70	38.10	36.90	36.20	34.70	39.60	40.60	36.45	2.44
IDF[2]	9.00	16.5	12.80	34.10	32.3	31.3	34.7	35.7	35.1	34.7	32.2	35.8	39	34.49	2.22
SDF[2]	–	2.00	1.10	1.10	1.80	1.90	2.00	2.40	1.80	1.50	2.50	3.90	1.50	2.04	0.77
Lignin	2.03	0.27	0.67	2.99	2.69	2.66	3.35	4.32	2.67	2.59	3.12	2.85	2.99	3.02	0.51
Ash	1.12	6.84	6.37	4.90	6.67	4.94	7.08	5.20	5.01	4.88	5.01	5.14	5.78	5.46	0.79
Ca	0.01	0.32	0.87	0.08	0.36	0.07	0.73	0.08	0.10	0.14	0.08	0.07	0.09	0.18	0.29
P	0.22	0.64	0.48	1.04	1.22	1.18	1.12	1.22	1.11	1.13	1.10	1.23	1.32	1.17	0.22
Carbohydrates															
Starch	62.83	0.98	42.98	21.53	18.92	23.30	20.02	16.53	21.58	21.52	22.39	20.63	16.33	20.28	2.36
FOS[2], mg/g	1.33	8.04	2.48	4.10	2.90	3.37	2.76	3.45	3.41	3.35	3.56	3.29	3.32	3.35	0.36
Glucose	0.24	0.07	0.16	0.37	0.33	0.30	0.35	0.30	0.26	0.29	0.30	0.27	0.35	0.31	0.04
Sucrose	1.88	7.41	1.37	1.38	1.99	2.17	1.07	2.21	1.94	1.93	2.14	2.28	2.11	1.92	0.39
Maltose	–	–	3.01	1.18	1.03	2.53	1.48	1.30	1.99	2.92	1.90	3.22	1.37	1.89	0.77
Fructose	0.15	0.07	0.27	0.56	0.39	0.30	0.33	0.30	0.34	0.35	0.41	0.35	0.40	0.37	0.08
Stachyose	–	6.46	–	–	–	–	–	–	–	–	–	–	–	–	–
Raffinose	0.22	1.73	0.58	0.69	0.89	1.00	0.24	1.07	0.94	0.94	1.34	0.97	1.16	0.92	0.29
Physical characteristics															
Bulk density, g/L	608.8	696.8	498.5	289.8	309.3	348.5	333.3	301.8	324.6	322.1	303.8	322.4	296.0	315.1	18.20
Particle size, µm	554	830	146	818	707	785	760	766	733	521	867	1019	848	782.4	127.3
SD particle size, (log_{10})	0.48	0.26	0.25	0.30	0.24	0.20	0.38	0.33	0.32	0.29	0.31	0.37	0.34	0.30	0.05
WBC[2], g/g	1.21	2.51	1.83	3.44	2.98	2.96	3.33	3.30	2.88	2.99	2.89	3.08	3.28	3.11	0.20

[1]Means and standard deviation for the 10 sources of wheat middlings.

[2]AEE, acid hydrolyzed ether extract; TDF, total dietary fiber; SDF, soluble dietary fiber; IDF, insoluble dietary fiber; FOS, fructooligosaccharides; WBC, water binding capacity.

Table 2. Ingredient composition of the basal corn-soybean diet and diets containing red dog or wheat middlings

	Diet	
Ingredient, %	Corn-soybean meal	Wheat middlings or red dog
Corn	65.00	39.00
Soybean meal, 48% CP	32.50	19.50
Wheat middlings or red dog	–	39.40
Limestone	0.95	1.40
Dicalcium phosphate	0.85	–
Sodium chloride	0.40	0.40
Vitamin mineral premix[1]	0.30	0.30

[1]The vitamin–micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D_3 as cholecalciferol, 2,208 IU; vitamin E as DL-α-tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydroiodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

Table 3. Analyzed composition (as-fed basis) of the basal corn-soybean diet and diets containing red dog or wheat middlings

			Wheat middlings, source									
Item	Basal	Red dog	1	2	3	4	5	6	7	8	9	10
GE, kcal/kg	3,876	3,846	3,875	3,836	3,904	3,871	3,851	3,935	3,908	3,903	3,931	3,914
DM	88.62	88.35	87.86	87.93	88.55	88.82	87.93	88.68	88.76	88.27	88.67	88.34
CP	22.44	21.41	19.94	20.91	18.95	19.08	18.76	19.83	19.43	20.07	19.28	19.96
AEE[1]	3.86	2.88	2.13	3.30	3.77	1.95	2.78	2.52	2.13	2.54	2.70	2.71
ADF	4.66	2.94	5.52	3.17	5.85	5.66	6.06	5.34	5.58	5.78	5.44	6.77
NDF	10.98	10.05	18.06	18.64	21.12	17.99	19.01	17.41	18.41	18.32	18.62	21.94
Lignin	1.38	1.20	1.79	1.87	1.67	1.70	2.23	2.03	1.81	1.59	1.91	1.95
Ash	4.87	6.67	5.82	6.36	6.54	6.54	5.48	6.13	5.77	5.81	4.72	5.57

[1]AEE, acid hydrolyzed ether extract.

(method 930.05; AOAC Int., 2007), ash (method 942.05, AOAC Int., 2007), and for NDF using Ankom Technology method 13 (Ankom 2000 Fiber Analyzer; Ankom Technology, Macedon, NY). Ingredients and diets were also analyzed for CP by the combustion procedure (method 990.03; AOAC Int., 2007) using an Elementar Rapid N-cube Protein/Nitrogen apparatus (Elementar Americas Inc, Mt Laurel, NJ). These samples were also analyzed for acid hydrolyzed ether extract (**AEE**) by acid hydrolysis using the acid hydrolysis filter bag technique (Ankom HCl Hydrolysis System, Ankom Technology, Macedon, NY) followed by fat extraction (Ankom XT-15 Extractor, Ankom Technology, Macedon, NY) and for ADF using Ankom Technology method 12 (Ankom 2000 Fiber Analyzer; Ankom Technology, Macedon, NY). Ingredients were analyzed for Ca and P (method 975.03; AOAC Int., 2007). Lignin was determined in ingredients and diets using Ankom Technology method 9 (Daisy[II] Incubator, Ankom Technology, Macedon, NY). Ingredients were also analyzed for starch (method 979.10; AOAC Int., 2007), fructooligosaccharides (**FOS**) using refractive index HPLC (Campbell et al., 1997), and for fructose, glucose, sucrose, maltose, stachyose, and raffinose (Janauer and Englmaier, 1978). Corn, soybean meal, red dog, and the 10 sources of wheat middlings were also analyzed for insoluble dietary fiber (**IDF**) and soluble dietary fiber (**SDF**) according to method 991.43 (AOAC Int., 2007) using the Ankom[TDF] Dietary Fiber Analyzer (Ankom Technology, Macedon, NY). Total dietary fiber (**TDF**) was calculated as the sum of IDF and SDF. Bulk density was determined as described by Cromwell et al. (2000), and water binding capacity was measured as described by Robertson et al. (2000). Particle size of the corn, soybean meal, red dog, and the 10 sources of wheat middlings was determined using 50 g of the ingredient that was placed on the top of test sieves and placed in a vibratory sieve shaker for 10 min. The feedstuff material in each of the test sieves was recorded and weighed for calculation of mean particle size (ANSI/ASAE, 2008).

Calculations and Statistical Analysis

Organic matter was calculated as the difference between DM and ash. The DE and ME and the ATTD of GE, DM, OM, and NDF in all diets were calculated using the direct procedure (Adeola, 2001). The contribution of energy from corn and soybean meal to the diets containing wheat middlings or red dog was subtracted from the DE and ME for these diets, and the DE and ME in each source of wheat middlings and red dog were calculated by difference (Adeola, 2001). The ATTD of GE, DM, OM, and NDF in each source of wheat middlings and in red dog was also calculated by difference.

Outliers were identified as values that deviated from the treatment mean by more than 3 times the interquartile range, using the PROC BOXPLOT option of SAS (SAS Institute Inc, Cary, NC). Normality of data was tested using the UNIVARIATE procedure in SAS. Data were analyzed as described by Casas and Stein (2017) using PROC GLM of SAS. Briefly, the 10 sources of wheat middlings were compared using ANOVA with diet or ingredient, period, and pig as the main effects. A LSD test was used to separate means. Values for red dog were compared with values for wheat middlings using an estimate statement. The pig was the experimental unit for all analyses. Differences were considered significant if $P < 0.05$.

RESULTS AND DISCUSSION

Wheat coproducts commonly are differentiated by the nutritional composition, mainly the concentration of starch and fiber (de Blas et al., 2010; Rostagno et al., 2011; NRC, 2012). In the United States, red dog is defined as the "tail of the mill" consisting mainly of the aleurone layer of the wheat grain with small particles of bran, germ, and flour and contains more than 4% crude fiber, whereas wheat middlings is described as a mix of wheat bran, wheat germ, wheat flour, and red dog (Blasi et al., 1998; AAFCO, 2000; Sauvant et al., 2004; Serna-Saldivar, 2010).

Chemical Composition of Wheat Middlings and Red Dog

The chemical composition of corn and soybean meal used in this experiment was in agreement with reported values (Almeida et al., 2011; NRC, 2012; Rojas et al., 2013; Rojas and Stein, 2013). The concentration of CP in the sources of wheat middlings used in this experiment was between 17.0% and 18.8%, and CP was also 17.0% in red dog (Table 1). These values are greater than previously reported (Cromwell et al., 2000; Sauvant et al., 2004; Rostagno et al., 2011; Huang et al., 2012; NRC, 2012; Huang et al., 2014). The AEE in wheat middlings ranged from 2.50% in source 1 to 4.71% in source 10; however, the SD was 0.77, indicating low variability in the concentration of AEE among the sources of wheat middlings. Likewise, the concentration of AEE in red dog was relatively low (2.50%) compared with wheat middlings. These values are greater than the value reported by NRC (2012) for wheat middlings but within the range of values reported elsewhere (Sauvant et al., 2004; Huang et al., 2012; 2014; Jaworski et al., 2015). Variation in the composition of wheat coproducts is a result of variations in the production process or differences among varieties of wheat, and differences in growing conditions of wheat may also affect the chemical composition of the wheat grain (Erickson et al., 1985).

Between 80 and 90% of the starch in wheat is extracted during flour milling, and the resulting wheat coproducts contain only 8 to 16% starch (Blasi et al., 1998). The observation that the average starch in the 10 sources of wheat middlings used in this experiment was 20.2% with relatively little variation indicate that flour mills in the United States may be less efficient in removal of starch than previously believed. However, the values obtained in this experiment are in agreement with the value reported by NRC (2012) and de Blas et al. (2010), but is less than reported by Sauvant et al. (2004); Rostagno et al. (2011); and Huang et al. (2014). The concentration of starch in red dog was 43%, which is less than the value reported for red dog from China (Huang et al., 2012, 2014). The reason red dog contains more starch than wheat middlings likely is that red dog contains a significant proportion of endosperm, which is high in starch.

Concentrations of NDF and TDF in wheat middlings averaged 35.51% and 36.45%, respectively, whereas red dog contained only 11.81% and 13.90% NDF and TDF. However, approximately 97% of the TDF was analyzed as IDF in wheat middlings, whereas 92% of TDF was analyzed as IDF in red dog. The average concentration of TDF in wheat middlings observed in this experiment is very close to the value reported by Jaworski and Stein (2017). The concentration of

ADF was 10.13% (±2.44%) among the 10 sources of wheat middlings and 3.37% in red dog, which is in agreement with reported values (Sauvant et al., 2004; Huang et al., 2012, 2014; NRC, 2012). The concentration of lignin, which ranged from 2.59% to 4.30% in wheat middlings, is in agreement with the value reported by Jaworski and Stein (2017). In contrast, the concentration of lignin in red dog was only 0.67%. In general, the concentration of fiber in wheat middlings increases as the concentration of starch decreases (Rosenfelder et al., 2013), which was also observed in this experiment.

The concentrations of glucose (0.31%), fructose (0.67%), and raffinose (0.92%) in wheat middlings were less than reported previously, but the concentrations of sucrose (1.92%) and maltose (1.89%) were greater than previous values (Jaworski and Stein, 2017). Fructoligosacharides are mixtures of 1-ketose, nystose, and 1-β-fructofuranosyl-nystose and have been identified in different sources of plant ingredients including wheat coproducts (Hussein et al., 1998). The concentration of FOS in wheat middlings used in this experiment was on average 3.35 mg/g and 2.48 mg/g in red dog. These values are less than reported by Campbell et al. (1997) and Hussein et al. (1998). It is possible that there are differences among varieties of wheat that account for these differences.

The concentration of ash, Ca, and P in the 10 sources of wheat middlings was 5.8 ± 0.8%, 0.18 ± 0.29%, and 1.17 ± 0.22%, respectively, which is within the range of reported values (Eeckhout and De Paepe, 1994; Blasi et al., 1998; NRC, 2012). Red dog contained more ash and Ca, but less P, than wheat middlings, which is likely a result of the reduced content of fiber in red dog. The concentration of total P in wheat coproducts is greater than in wheat, but most of the P is bound to phytate, because the majority of phytate is located in the aleurone layer of most cereal grains (Eeckhout and De Paepe, 1994; Slominski et al., 2004).

Physical Characteristics of Wheat Middlings and Red Dog

Bulk density and particle size of ingredients may influence feed intake of pigs and affect the utilization of energy (Kyriazakis and Emmans, 1995; Rojas et al., 2016). Likewise, water binding capacity may negatively affect the digestibility of starch and AA (Jaworski and Stein, 2017). The bulk density of the sources of wheat middlings used in this experiment ranged from 289 to 333 g/L, which concurs with the values reported by Cromwell et al. (2000), but is less than reported by Jaworski and Stein (2017). Cromwell et al. (2000) concluded that wheat middlings with bulk density greater than 335 g/L usually contains more starch than if the bulk density is less than 335 g/L, which concur with the observation that red dog had a greater bulk density (498 g/L) than wheat middlings and also contained more starch.

Wheat middlings had low bulk density compared with the bulk density of corn, which may result in difficulties when handling and storing wheat middlings, and it is possible that special equipment and bins are required to handle wheat middlings. Alternatively, wheat middlings may be pelleted to reduce dust and losses during storage and loading and to improve handling (Blasi et al., 1998).

The particle size of the 10 sources of wheat middlings was 782 ± 83 µm, and the particle size of red dog was 146 µm. The water binding capacity was 3.11 ± 0.2 g/g in wheat middlings and 1.83 g/g in red dog. These values concur with reported values (Jaworski and Stein, 2017).

Digestibility of GE, DM, OM, and NDF in Diets and Ingredients and Concentration of DE and ME

There were no differences in GE intake or GE output in urine among diets containing the 10 sources of wheat middlings or between the diets containing wheat middlings and the diet containing red dog (Table 4). However, the GE in feces was greater ($P < 0.05$) from pigs fed diets containing wheat middlings than from pigs fed the diet with red dog. The average ATTD of GE, DM, OM, and NDF was 80.3, 81.4, 83.3, and 56.2%, respectively, in diets containing wheat middlings, which was less ($P < 0.05$) than in the diet containing red dog (89.4, 90.5, 91.9, and 67.0%). Differences in the ATTD of GE and NDF ($P < 0.05$) were observed among diets containing wheat middlings. However, the LSD and SEM values for these variables were low, indicating that ATTD of GE and nutrients in these diets was relatively consistent.

The ATTD of GE, DM, OM, and NDF in wheat middlings was 67.2, 71.2, 72.9, and 53.0%, respectively (Table 5), but differences ($P < 0.05$) among sources of wheat middlings were observed indicating that variation in nutrient composition may affect nutrient digestibility. The ATTD of GE and DM obtained in this experiment is greater than reported by Nortey et al. (2008) but concur with values reported by Jaworski and Stein (2017) and by Huang et al. (2014).

Table 4. ATTD (%) of GE, DM, OM, and NDF, and concentration of DE and ME in the basal corn-soybean meal diet and in diets containing wheat middlings or red dog[1]

			Wheat middlings, source												Wheat middlings[2]			Red dog vs. wheat middlings[3]	
Item	Basal	Red dog	1	2	3	4	5	6	7	8	9	10	Mean[4]	SD[4]	SEM	LSD	*P*-value	SEM	*P*-value
GE intake, kcal/d	8,589	9,018	8,923	8,997	9,253	8,989	8,759	9,152	9,110	9,072	8,915	8,984	9,015	139	133.9	368.6	0.37	140.6	0.986
GE in feces, kcal/d	905	1,290	1,696	1,718	1,763	1,803	1,884	1,702	1,735	1,664	1,753	1,717	1,743	62.9	58.2	160.5	0.37	66.7	<0.001
GE in urine, kcal/d	430	362	326	363	347	352	349	377	360	307	364	347	349	20.1	31.2	85.7	0.93	33.5	0.712
ATTD of GE, %	89.4	85.5	80.8	80.7	80.5	79.7	78.1	81.2	80.7	81.5	80.2	79.6	80.3	0.97	0.41	1.13	<0.001	0.49	<0.0001
ATTD of DM, %	90.5	87.1	81.1	81.5	82.4	80.0	80.5	81.2	82.6	81.8	81.8	81.1	81.4	0.79	0.46	1.27	0.01	0.50	<0.001
ATTD of OM, %	91.9	89.1	83.0	83.4	84.0	82.1	82.5	83.2	84.4	83.7	83.9	83.0	83.3	0.7	0.42	1.15	0.01	0.46	<0.0001
ATTD of NDF, %	67.0	63	53.0	55.2	61.5	55.7	56.9	50.7	61.8	58.3	54.2	54.3	56.2	3.56	1.08	2.96	<0.001	1.63	<0.0001
DE, kcal/kg	3,464	3,288	3,131	3,097	3,142	3,086	3,009	3,197	3,154	3,182	3,154	3,117	3,127	54.1	15.9	43.85	<0.001	18.8	<0.0001
ME, kcal/kg	3,275	3,136	2,990	2,943	2,997	2,942	2,864	3,039	3,005	3,049	3,001	2,969	2,980	54.0	19.3	53.12	<0.001	23.5	<0.0001

[1]Values are least square means of eight observations per treatment.

[2]Comparison among the 10 diets containing wheat middlings.

[3]Comparison of diets containing red dog vs. the 10 diets containing wheat middlings.

[4]Mean and SD for the 10 diets containing wheat middlings.

Table 5. ATTD (%) of GE, DM, OM, and NDF, and concentration of DE and ME in wheat middlings and red dog[1]

Item	Red dog	Wheat middlings, source												Wheat middlings[2]			Red dog vs. wheat middlings[3]	
		1	2	3	4	5	6	7	8	9	10	Mean[4]	SD[4]	SEM	LSD	*P*-value	SEM	*P*-value
ATTD of GE, %	79.3	68.6	68.1	66.4	66.0	61.9	69.7	68.1	70.3	67.2	65.5	67.2	2.42	0.91	2.5	<0.001	1.10	<0.001
ATTD of DM, %	82.9	70.4	71.3	73.4	68.7	69.3	71.3	73.6	72.2	72.4	68.9	71.2	1.80	0.81	2.22	<0.001	0.90	<0.001
ATTD of OM, %	86.6	72.3	72.8	74.6	70.1	70.9	73.0	75.6	74.1	74.9	70.5	72.9	1.93	0.79	2.18	<0.001	0.90	<0.001
ATTD of NDF, %	58.7	48.9	51.7	59.9	52.7	54.3	45.4	60.4	55.7	50.2	51.0	53.0	4.71	1.38	3.79	<0.001	2.00	<0.001
DE, kcal/kg	3,050	2,674	2,576	2,644	2,561	2,353	2,844	2,725	2,801	2,733	2,626	2,654	140	37	103	<0.001	44.2	<0.001
DE, kcal/kg, DM basis	3,408	3,104	2,933	2,956	2,847	2,637	3,185	3,070	3,182	3,052	2,933	2,990	167	42	116	<0.001	49.7	<0.001
ME, kcal/kg	2,945	2,600	2,473	2,570	2,482	2,272	2,729	2,632	2,751	2,631	2,537	2,568	139	48	131	<0.001	53.5	<0.001
ME, kcal/kg, DM basis	3,292	3,018	2,816	2,874	2,759	2,547	3,056	2,966	3,126	2,938	2,833	2,893	167	54	147	<0.001	60.3	<0.001

[1]Values are least square means of eight observations per treatment.

[2]Comparison among the 10 sources of wheat middlings.

[3]Comparison of red dog vs. the 10 sources of wheat middlings.

[4]Mean and SD for the 10 sources of wheat middlings.

The concentration of DE in wheat middlings ranged from 2,353 to 2,844 kcal/kg, and the concentration of ME ranged from 2,272 to 2,729 kcal/kg. These values are less than reported values (Sauvant et al., 2004; NRC, 2012). However, the concentration of DE on a DM basis ranged from 2,637 to 3,185 kcal/kg, and the concentration of ME on a DM basis varied between 2,547 and 3,056 kcal/kg, and these values are in agreement with values reported by Nortey et al. (2008).

The ATTD of GE, DM, OM, and NDF in red dog was 79.3, 82.9, 86.6, and 58.7% respectively, which is less than reported for red dog from China (Huang et al., 2012, 2014), but ATTD of GE, DM, OM, and NDF was greater ($P < 0.05$) in red dog than in the 10 sources of wheat middlings, which is in agreement with Huang et al. (2014). Concentrations of DE in red dog were 3,050 and 3,408 kcal/kg (as-fed and DM basis, respectively), and concentrations of ME (as-fed basis and DM basis) were 2,945 and 3,292 kcal/kg, respectively. These values are less than reported by Huang et al. (2012). However, the concentrations of DE and ME were greater ($P < 0.05$) in red dog than in wheat middlings, which likely is a consequence of the greater concentration of starch and reduced concentrations of NDF in red dog compared with wheat middlings. It is also possible that the smaller particle size in red dog increased the ATTD of GE in red dog compared with wheat middlings (Rosenfelder et al., 2013; Rojas and Stein, 2015).

In conclusion, nutrient composition of the wheat middlings used in this experiment generally had limited variability, but the fractions that were most variable were the concentration of starch, NDF, and TDF. The concentration of starch in red dog was greater than in wheat middlings, but the concentration of NDF and TDF was less. Variation in ATTD of GE and nutrients among the 10 sources of wheat middlings was low, but the ATTD of GE and nutrients in red dog was greater than in wheat middlings. Differences in physical characteristics and concentration of starch and fiber are likely the main reason for the greater nutritional value observed of red dog compared with wheat middlings.

LITERATURE CITED

AAFCO. 2000. Official Publication. Association of American Feed Control Officials. Oxford, IN.

Adeola, O. 2001. Digestion and balance techniques in pigs. In: Lewis A.J., and L.L. Southern, editors. Swine nutrition. Washington (DC): CRC Press; p. 903–916.

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

ANSI/ASAE. 2008. Method of determining and expresing finess of feed materials by sieving (ANSI/ASAE S319.4). New York (NY): American National Standards Institute.

AOAC International. 2007. In: W. Hortwitz and G. W. Latimer, Jr., eds. Official methods of analysis of AOAC Int. 18th ed. Rev. 2. ed. Gaithersburg, MD: AOAC Int.

Bach Knudsen, K. E. 1997. Carbohydrate and lignin contents of plant materials used in animal feeding. Anim. Feed Sci. Technol. 67:319–338. doi:10.1016/S0377-8401(97)00009-6

de Blas, C., G. G. Mateos, and P. García-Rebollar. 2010. Tablas FEDNA de composición y valor nutritivo de alimentos para la fabricación de piensos compuestos. (In spanish). 3rd. ed. Madrid, Spain: Fundación Española Desarrollo Nutrición Animal.

Blasi, D. A., G. L. Kuhl, J. S. Drouillard, C. L. Reed, D. M. Trigo-Stockli, K. C. Behnke, and F. J. Fairchild. Wheat middlings. Composition, feeding value, and storage guidelines. Kansas State University Agricultural Experiment Station and Cooperative Extension. 1998. [accessed August 15, 2017]. http://www.bookstore.ksre.ksu.edu.]

Bond, J., and O. Liefert. Wheat outlook. WHS-17g. 2017. [accessed August 15, 2017]. http://www.ers.usda.gov/publications.

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

Casas, G. A., and H. H. Stein. 2017. The ileal digestibility of most amino acids is greater in red dog than in wheat middlings when fed to growing pigs. J. Anim. Sci. 95:2718–2725. doi:10.2527/jas.2017.1515

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. J. Anim. Sci. 78:2652–2658. doi:10.2527/2000.78102652x

Eeckhout, W., and M. De Paepe. 1994. Total phosphorus, phytate-phosphorus and phytase activity in plant feedstuffs. Anim. Feed Sci. Technol. 47:19–29. doi:10.1016/0377-8401(94)90156-2

Erickson, J. P., E. R. Miller, P. K. Ku, G. F. Collings, and J. R. Black. 1985. Wheat middlings as a source of energy, amino acids, phosphorus and pellet binding quality for swine diets. J. Anim. Sci. 60:1012–1020. doi:10.2527/jas1985.6041012x

Huang, Q., X. S. Piao, P. Ren, and D. F. Li. 2012. Prediction of digestible and metabolizable energy content and standardized ileal amino acid digestibility in wheat shorts and red dog for growing pigs. Asian-Australas. J. Anim. Sci. 25:1748–1758. doi:10.5713/ajas.2012.12298

Huang, Q., C. X. Shi, Y. B. Su, Z. Y. Liu, D. F. Li, L. Liu, C. F. Huang, X. S. Piao, and C. H. Lai. 2014. Prediction of the digestible and metabolizable energy content of wheat milling by-products for growing pigs from chemical composition. Anim. Feed Sci. Technol. 196:107–116. doi:10.1016/j.anifeedsci.2014.06.009

Hussein, H. S., J. M. Campbell, L. L. Bauer, G. C. Fahey, A. J. C. L. Hogarth, B. W. Wolf, and D. E. Hunter. 1998. Selected fructooligosaccharide composition of pet-food ingredients. J. Nutr. 128:2803S–2805S.

Janauer, G. A., and P. Englmaier. 1978. Multi-step time program for the rapid gas-liquid chromatography of carbohydrates. J. Chromatogr. A. 153:539–542. doi:10.1016/S0021-9673(00)95518-3

Jaworski, N. W., and H. H. Stein. 2017. Disappearance of nutrients and energy in the stomach and small intestine, cecum, and colon of pigs fed corn-soybean meal diets containing distillers dried grains with solubles, wheat middlings, or soybean hulls. J. Anim. Sci. 95:727–739. doi:10.2527/jas.2016.0752

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

Kim, B. G., G. I. Petersen, R. B. Hinson, G. L. Allee, and H. H. Stein. 2009. Amino acid digestibility and energy concentration in a novel source of high-protein distillers dried grains and their effects on growth performance of pigs. J. Anim. Sci. 87:4013–4021. doi:10.2527/jas.2009–2060

Kyriazakis, I., and G. C. Emmans. 1995. The voluntary feed intake of pigs given feeds based on wheat bran, dried citrus pulp and grass meal, in relation to measurements of feed bulk. Br. J. Nutr. 73:191–207. doi:10.1079/BJN19950023

Nortey, T. N., J. F. Patience, J. S. Sands, N. L. Trottier, and R. T. Zijlstra. 2008. Effects of xylanase supplementation on the apparent digestibility and digestible content of energy, amino acids, phosphorus, and calcium in wheat and wheat by-products from dry milling fed to grower pigs. J. Anim. Sci. 86:3450–3464. doi:10.2527/jas.2007-0472

NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Washington (DC): The National Academies Press.

Nyachoti, C. M., J. D. House, B. A. Slominski, and I. R. Seddon. 2005. Energy and nutrient digestibilities in wheat dried distillers' grains with solubles fed to growing pigs. J. Sci. Food Agric. 85:2581–2586. doi:10.1002/jsfa.2305

Robertson, J. A., F. D. de Monredon, P. Dysseler, F. Guillon, R. Amado, and J.-F. Thibault. 2000. Hydration properties of dietary fibre and resistant starch: a European collaborative study. Lebensm.-Wiss. Technol. 33:72–79. doi:10.1006/fstl.1999.0595

Rojas, O. J., and H. H. Stein. 2013. Concentration of digestible, metabolizable, and net energy and digestibility of energy and nutrients in fermented soybean meal, conventional soybean meal, and fish meal fed to weanling pigs. J. Anim. Sci. 91:4397–4405. doi:10.2527/jas.2013–6409

Rojas, O. J., and H. H. Stein. 2015. Effects of reducing the particle size of corn grain on the concentration of digestible and metabolizable energy and on the digestibility of energy and nutrients in corn grain fed to growing pigs. Livest. Sci. 181:187–193. doi:10.1016/j.livsci.2015.09.013

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

Rojas, O. J., Y. Liu, and H. H. Stein. 2016. Effects of particle size of yellow dent corn on physical characteristics of diets and growth performance and carcass characteristics of growing-finishing pigs. J. Anim. Sci. 94:619–628. doi:10.2527/jas2015-9054

Rosenfelder, P., M. Eklund, and R. Mosenthin. 2013. Nutritive value of wheat and wheat by-products in pig nutrition: a review. Anim. Feed Sci. Technol. 185:107–125. doi:10.1016/j.anifeedsci.2013.07.011

Rostagno, H. S., L. F. T. Albino, J. L. Donzele, P. C. Gomes, R. F. de Oliveira, D. C. Lopes, A. S. Ferreira, S. L. T. Barreto, and R. F. Euclides. 2011. Brazilian tables for poultry and swine. Composition of feedstuffs and nutritional requirements. 3rd ed. Viçosa, Brazil: Universidade Federal de Viçosa.

Sauvant, D., J. M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses and fish. 2nd ed. Wageningen, The Netherlands: Wageningen Academic Publishers.

Serna-Saldivar, S. O. 2010. Cereal grains. Properties, processing, and nutritional attributtes. Boca Raton (FL): CRC Press.

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. doi:10.4141/A03-112

Zijlstra, R. T., and E. Beltranena. 2013. Swine convert co-products from food and biofuel industries into animal protein for food. Anim. Frontiers. 3:48–53. doi:10.2527/af.2013-0014