RESEARCHREPORT
ANIMAL SCIENCE

Title: Energy and nutrient digestibility in 11 sources of wheat middlings – **NPB #15-114**

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Date Submitted: Jan. 14, 2017

Industry Summary

Wheat middlings and red dog are co-products from the wheat processing industry and are the high-fiber leftovers from production of wheat flour. There is an estimated total annual production of 6 to million tons of wheat coproducts produced in the U.S. and much of that amount is used in the feeding of swine. There has, however, been very little research conducted to determine the nutritional value of wheat coproducts fed to pigs. The present research determined, in 2 experiments, the ileal digestibility of amino acids in 10 sources of wheat middlings that were collected throughout the U.S. and in one source of red dog. The concentrations of DE and ME were also determined and equations to predict the concentration of DE and ME in wheat middlings were developed as well.

Results indicated that red dog has greater digestibility of amino acids and also contains more DE and ME than wheat middlings. All sources of wheat middlings had relatively low digestibility of lysine indicating that high amounts of heat most likely is applied to these ingredients during the production process. The digestibility of all fiber components is also greater in red dog than in wheat middlings. The reason for the greater concentration of DE and ME in red dog is most likely that this ingredient contains twice as much starch

and much less fiber than wheat middlings. These differences in composition are likely also the reason for the greater digestibility of AA in red dog than in wheat middlings. As a consequence, red dog has a greater nutritional value in diets for pigs. Data from this research provide, for the first time, a robust estimate of digestibility values for AA and energy in wheat middlings and for one source of red dog. These values may be used in formulation of diets for pigs.

Overall conclusions:

- Wheat middlings selected from across the U.S. has a relatively constant nutrient composition
- Wheat middlings has a relatively high concentration of fiber and a low concentration of starch.
- The digestibility of amino acids and the concentration of metabolizable energy in wheat middlings is less than previously thought
- Red dog has a greater digestibility of amino acids and contains more metabolizable energy than wheat middlings due to a greater concentration of starch and a reduced concentration of fiber compared with wheat middlings

Keywords: amino acid digestibility, energy, fiber, pigs, red dog, wheat middlings

Scientific Abstract

Two experiments were conducted. Exp. 1 was conducted to determine the standardized ileal digestibility (SID) of CP and AA in 10 sources of wheat middlings and in one source of red dog, and Exp. 2 was conducted to determine the apparent total tract digestibility (ATTD) of energy and fiber in the same ingredients. In Exp. 1, 10 diets that each contained one of the 10 sources of wheat middlings and 1 diet that contained red dog as the only source of protein and AA were formulated. An N-free diet was used to determine basal endogenous losses of CP and AA. Twelve pigs (BW: 29.23 ± 1.5 kg) were fitted with a T-cannula in the distal ileum. Pigs were allotted to a 12 × 8 Youden square design with 12 diet and eight 7-d periods. The initial 5 d of each period was the adaptation period, but ileal digesta were collected on the last 2 d of each period. In Exp. 2, 12 diets were also formulated with 1 diet being based on corn and soybean meal, and 11 diets were formulated by mixing corn and soybean meal and 39.5% of red dog or each source of wheat middlings. Twelve pigs were placed in metabolism crates and allotted to a 12 x 8 Youden square design with 12 diets and 8 14-d periods. In each period, feces and urine were collected for 5 d following 7 d of adaptation. Results of Exp. 1 indicated that the average SID of CP in wheat middlings was 61.2 ± 4.9% and there were no differences among the 10 sources of wheat middlings. However, the SID of CP in red dog (78.5%) was greater ($P < 0.05$) than in wheat middlings. The SID of Arg, His, and Asp in wheat middlings was 81.4 ± 2.7%, 77.7 ± 2.1%, and 66.4 ± 2.7%, respectively, and no differences among sources of wheat middlings were observed for these AA. The SID of Met (73.6 ± 1.9%) and the SID of Ala (54.8 ± 4.9%) tended ($P = 0.071$ and 0.090, respectively) to be different among sources of wheat middlings, and the SID of all other AA was different ($P < 0.05$) among the 10 sources of wheat middlings. There were no differences between red dog and wheat middlings for the SID of Arg, His, and Ser, and the SID of Cys was less ($P < 0.05$) in red dog than in wheat middlings, but for all other AA, the SID in red dog was greater ($P < 0.05$) than in wheat middlings. Results of Exp. 2 indicated that the average DE and ME in the 10 sources of wheat middlings were 2,990 and 2,893 kcal/kg DM, respectively, but DE and ME in red dog (3,414 and 3,300 kcal/kg DM, respectively) were greater ($P < 0.05$) than in wheat middlings. The ATTD of GE, DM, OM, ADF, and NDF were also greater ($P < 0.05$) in red dog than in wheat middlings. Both DE and ME in wheat middlings could be predicted relatively accurately (r2 = 0.95 and 0.93, respectively) from concentrations of GE, CP, AEE, ADF, NDF, lignin, ash and starch.

In conclusion, the AA composition of wheat middlings and red dog is similar, but the concentrations of AA are greater in both ingredients than previously reported. The SID of CP and AA in red dog are greater than in wheat middlings. Likewise, values for DE and ME in wheat middlings are less than some previous reports, but are greater in red dog than in wheat middlings.

V. Introduction

Wheat is the third most important crop (after maize and soybeans) produced in the U.S. if measured based on acres harvested (USDA, 2016). Most wheat is used for human consumption and between 70 and 75% of the wheat grain becomes flour, and the 25 to 30% of the wheat grains that are not used for human consumption may be used in animal feeding (Blasi et al., 1998). Red dog is a coproduct from 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 (Blasi et al., 1998; AFFCO, 2000). Wheat middlings consists of particles of wheat bran, wheat germ, wheat flour, and fractions of wheat shorts (AAFCO, 2000; Sauvant et al., 2004). The composition and nutritional value of wheat coproducts depend on the proportion of bran and flour that are included in the product, the characteristics of the original wheat, and the milling process (Cromwell et al., 2000; Huang et al., 2012; Rosenfelder et al., 2013). The concentration of protein in wheat middlings is between 16 and 18%, which is greater than in whole wheat grain. Albumins and globulins represent 20 to 25% of total proteins in wheat grains, whereas the gluteins and gliadins or prolamins are 75 to 80 % (Rosenfelder et al., 2013). The relatively high concentration of fiber in wheat coproducts also may affect the digestibility of AA (Lenis et al., 1996). The digestibility of energy and nutrients in wheat by-products produced in Canada and China has been reported (Nyachoti et al., 2005; Huang et al., 2012), but there is limited information about the nutritional value of wheat middlings and red dog produced in the U.S.

VI. Objectives

The objective of this research was to determine the ileal digestibility of AA and the apparent total tract digestibility of energy, DM, ADF, and NDF in 10 different sources of wheat middlings and one source of red dog collected throughout the U.S. The concentration of DE and ME was also calculated in these sources and regressions equations were developed to estimate DE and ME in wheat middlings from the chemical composition.

MATERIALS AND METHODS

Two experiments were conducted and the protocol for each 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 experiments was produced in IA and the 10 sources of wheat middlings was produced in CO, IA, IL, KS, MI, MN, OH, or PA (Table 1).

Exp. 1. Amino acid digestibility

Animals and Housing. Twelve pigs that were the offspring of Line 359 boars mated to Camborough F-1 sows (Pig Improvement Company, Hendersonville, TN) with an average initial BW of 29.23 ± 1.5 kg were used. Pigs were surgically fitted with a T-cannula in the distal ileum (Stein et al., 1998) and allotted to a 12 × 8 Youden square design with 12 dietary treatments and eight 7-d periods. Each pig was individually housed in a 1.2 × 1.5 m pen that was equipped with a feeder and a nipple drinker. Pens had smooth, plastic-coated sides, and a fully slatted tribar metal floor. A feeder and a nipple drinker were installed in each pen. Pig weights were recorded at the beginning of each period.

Diets and Feeding. Twelve diets were formulated; 10 diets contained one source of wheat middlings and 1 diet contained red dog as the only source of protein and AA, and the last diet was an N-free diet that was used to determine basal endogenous losses of CP and AA (Tables 2 and 3). All diets contained vitamins and minerals in concentrations that exceeded the requirements for growing pigs (NRC, 2012). Chromic oxide (0.4%) was added to all diets as an indigestible marker. The daily feed allowance was calculated as 3 times the maintenance energy requirement (197 kcal/kg BW0.60; NRC, 2012) and divided into 2 equal meals that were provided at 0800 and 1600 h. Feed allowance for each pig was adjusted at the start of each period. Because all diets contained AA in quantities below the requirements for growing pigs (NRC. 2012), an AA mixture was prepared (Table 4). During the initial 5 d of each period, 75 g of this mixture was added to each meal, but no AA were added on d 6 and 7 of each period (Pedersen et al., 2007). Water was available at all times throughout the experiment.

Sample Collection. Each period consisted of 5 d of adaptation to the diets followed by 2 d of ileal digesta collection where collection was initiated immediately after feeding the morning meal and ceased before feeding the afternoon meal. For collection of samples, a 232 mL plastic bag was attached to the cannula barrel using a cable tie. Bags were removed when they were full or every 30 min and stored at -20°C to prevent bacterial degradation of AA. At the conclusion of each period, ileal samples were thawed at room temperature and mixed within animal and a sub-sample was collected. Digesta samples were lyophilized and finely ground prior to chemical analysis.

Chemical Analyses. Ingredients, diets, and ileal digesta samples were analyzed in duplicate for DM (Method 930.05; AOAC International, 2007), CP by combustion (Method 990.03; AOAC International, 2007) using an Elementar Rapid N-cube Protein/Nitrogen apparatus (Elementar Americas Inc., Mt Laurel, NJ), and for AA [Method 982.30 95 E (a, b, c); AOAC International, 2007]. Diets and ileal digesta samples were also analyzed for Cr (Method 990.09; AOAC International, 2007). Ingredients were analyzed in duplicate for ash (Method 942.05, AOAC International, 2007), and GE using an isoperibol bomb calorimeter (Model 6300, Parr Instruments, Moline, IL) with benzoic acid serving as the standard for calibration. Ingredients were also analyzed for ADF, NDF, and lignin using Ankom Technology method 12, 13, and 9, respectively (Ankom 2000 Fiber Analyzer; DaisyII Incubator, Ankom Technology, Macedon, NY) and for Ca, and P (Method 985.01; AOAC International, 2007).

Calculations and Statistical Analysis. Values for AID and SID of AA in each diet were calculated (Stein et al., 2007), and because the wheat co-products were the only AA containing ingredients in the diets, these values also represented the AID and SID for each wheat coproduct. Normality of data was verified and outliers were identified using the UNIVARIATE procedure (SAS Inst. Inc., Cary, NC). Outliers were identified as values that deviated from the treatment mean by more than 3 times the interquartile range. Data were analyzed by ANOVA using PROC GLM of SAS. The 10 sources of wheat middlings were compared using ANOVA with wheat co-product, pig, and period as the main effects. An LSD test was used to separate means. Values for red dog were compared with values for wheat middlings using a contrast statement. The pig was the experimental unit for all analyses. Differences were considered significant if $P < 0.05$ and were describe as a tendency if $0.05 < P < 0.1$.

Exp. 2. Energy and Fiber Digestibility

Animals and Housing. Twelve growing pigs that were the offspring of Line 359 boars mated to C-46 sows (Pig Improvement Company, Hendersonville, TN) with an average initial BW of 31.0 ± 1 kg were randomly allotted to 12 dietary treatments in 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 the total collection of feces and urine.

Diets and Feeding. A basal diet based corn and soybean meal, and 10 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 formulated (Tables 5 and 6). Each source of wheat middlings or red dog was included at 39.5 % in the diets. The wheat middlings and corn and soybean meal were the only sources of energy in the 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 (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. Each period lasted 14 d. Pigs were weighted at the beginning and at the end of each period. The initial 7 d of each period were considered an adaptation period to the diet. Fecal markers were fed in the morning meals on d 8 (chromic oxide) and d 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 -20ºC as soon as collected. Urine collection started on d 8 at 1700 h and ceased on d 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 -20º C. At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet and subsamples were collected for energy analysis. Fecal samples were dried at 65ºC in a forced air oven, ground through a 1 mm screen and urine samples were lyophilized before energy analysis as described by Kim et al. (2009).

Chemical Analyses. Ingredients, diets, fecal samples and urines samples were analyzed in duplicate for GE as explained for Exp. 1 (Table 7). Ingredients, diets, and fecals were analyzed in duplicate for DM, ash, CP, ADF and NDF, as explained for Exp. 1. Ingredients were analyzed for starch (Method 979.10; AOAC, 2007) and for fructose, glucose, sucrose, maltose, stachyose, and raffinose (Janauer and Englmaier, 1978). Ingredients and diets were also analyzed for AEE, Ca, and P as explained for Exp. 1. 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 sources of wheat middlings was determined using 50 g of the ingredient that was placed on the top of the 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 calculations 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, and NDF in diets were calculated using the direct procedure (Adeola, 2001). The contribution of the basal diet to the diets containing wheat middlings or red dog was subtracted from the values for these diets and the DE and ME were calculated by difference for each source or wheat middlings or red dog (Adeola, 2001). The ATTD of GE, DM, OM, and NDF were also calculated by difference.

Outliers and homogeneity of the variances among treatments were tested using the UNIVARIATE procedure (Version 9.4: SAS Institute, Inc. Cary, NC). Data were analyzed by ANOVA using PROC GLM of SAS (SAS Inst. Inc., Cary, NC). The 10 sources of wheat middlings were compared using ANOVA with the source of wheat middlings, pig, and period as main effects. The LSD test was used to separate means if they were different. The pig was the experimental unit for all analyses. An alpha level of 0.05 was used to consider significance among dietary treatments. Values for red dog were compared with values for wheat middlings using a contrast statement. Regression equations to estimate the relationship between DE, ME and chemical composition of wheat middlings were generate using the REG procedure in SAS (Pedersen et al., 2007).

RESULTS AND DISCUSSION

Exp. 1. Amino Acid Digestibility

Composition of Wheat Middlings and Red Dog. The concentration of protein in wheat middlings varied between 17.0 and 18.8 % and was also 17.0% in red dog. 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). The concentration of indispensable AA in the 10 sources of wheat middlings was also very consistent. The concentrations of Lys and Met were on average 0.72 and 0.25% in wheat middlings, but 0.63 and 0.37% in red dog. Lower concentration of Lys in wheat middlings were reported previously (Cromwell et al., 2000; Rostagno et al., 2011; NRC, 2012). Greater concentrations of Val, but lower concentrations of Arg, Ile, Lys, Met, and Thr were reported for Chinese red dog, (Huang et al., 2012). The Lys:CP ratio was 4.05 and 3.7 for wheat middlings and red dog, respectively. The concentration of AA in wheat middlings and red dog were similar. The high concentrations of Arg, Asp, and Glu in wheat middlings and red dog has been previously reported (Huang et al., 2012; Rosenfelder et al., 2013) and the AA profile in wheat middlings is comparable to values reported for rice bran (Casas et al., 2015). The reason for this observation may be that the main proteins in both ricebran and wheat middlings are albumin and globulins, which are the major protein in the outer layer of cereal grains (Rosenfelder et al., 2013). Likewise, greater concentration of Lys, Arg, and Asp in wheat middlings than in wheat DDGS have been reported (NRC, 2012; Rosenfelder et al., 2013).

The concentration of NDF in wheat middlings varied between 33.08% and 40.28%, whereas the concentration of NDF in red dog was 11.81%. The concentration of ADF was 10.81% on average for wheat middlings and 3.37% in red dog. These values are within the range of previously reported values (Cromwell et al., 2000; Rostagno et al., 2011; Huang et al., 2012; NRC, 2012). Lower concentration of NDF, ADF, and lignin in red dog compared with wheat shorts or wheat middlings has been reported (Huang et al., 1999; Huang et al., 2012; NRC, 2012) and is a consequence of less bran and more of the aleurone layer being included in red dog than in wheat middlings. However, concentrations of NDF, ADF, and lignin in wheat middlings are less than in wheat bran (Jaworski et al., 2016). Variation in the composition of wheat coproducts is a result of variations among flour mills in the production process and may also be influenced by the varieties of wheat that was used as well as growing conditions of wheat (Erikson et al., 1985)

Digestibility of Crude Protein and Amino Acids. The AID of CP in wheat middlings was on average 31.25%, but the SD was 7.25 (Table 8). The AID of CP in red dog was greater ($P < 0.05$) than the average for wheat middlings. The variation in AID of indispensable and dispensable AA in wheat middlings was less than the variation observed for the AID of CP. The AID of indispensable AA ranged between 30.3% for Lys to 67.7% for His and the AID of indispensable AA in red dog ranged from 53.7% in Val to 86.1% for Met. The AID of Arg and His in wheat middlings was 60.7% and 67.7%, respectively, and no differences were observed among sources. There was a tendency ($P = 0.059$) for differences among sources of wheat middlings for the AID of Lys and Asp, and for all other indispensable AA, differences ($P < 0.05$) among sources were observed. The AID of Arg and Ser was not different between wheat middlings and red dog, but the AID of His and Cys was greater ($P < 0.05$) in wheat middlings than in red dog. However, for all other AA, red dog had greater ($P < 0.05$) AID than wheat middlings.

The average SID of CP in wheat middlings was 61.2 ± 4.9% and there were no differences among the 10 sources of wheat middlings (Table 9). However, the SID of CP in red dog (78.5%) was greater ($P < 0.05$) than in wheat middlings. The SID of Arg, His, and Asp in wheat middlings was 81.4 ± 2.7%, 77.7 ± 2.1%, and 66.4 ± 2.7%, respectively, and no differences among sources of wheat middlings were observed for these AA. The SID of Met (73.6 ± 1.9%) and the SID of Ala (54.8 ± 4.9%) tended ($P = 0.071$ and 0.090, respectively) to be different among sources of wheat middlings, and the SID of all other AA was different ($P < 0.05$) among the 10 sources of wheat middlings. There were no differences between red dog and wheat middlings for the SID of Arg, His, and Ser, and the SID of Cys was less ($P < 0.05$) in red dog than in wheat middlings, but for all other AA, the SID in red dog was greater ($P < 0.05$) than in wheat middlings.

The AID and SID values of CP and AA in wheat middlings and red dog that were determined in the present experiment were less than values previously reported (Nortey et al., 2008; Huang et al., 2012). Likewise, the AID values of AA were less than the values reported for other wheat by-products such as wheat DDGS, wheat shorts, millrun, and wheat bran (Yin et al., 2000; Nyachoti et al., 2005; Nortey et al., 2008; Huang et al., 2012). Compared with other cereal coproducts commonly used in diets for pigs, such as rice bran or corn coproducts, the wheat middlings evaluated in this experiment had lower AID and SID of AA and CP (Almeida et al., 2011; Casas et al., 2015). The values for AID and SID of AA in wheat middlings obtained in the present experiment were also less than values reported by NRC (2012), but the NRC (2012) value was based on only one observation. However, the greater digestibility of CP and AA observed in red dog compared with wheat middlings may be explained by the lower concentration of NDF and ADF in red dog because a negative correlation between the concentration of fiber and the digestibility of AA in wheat coproducts has been reported (Huang et al., 1999). In addition, physical properties of the fiber in wheat by-products such as solubility, viscosity, and water holding capacity may influence the digestibility of AA (Souffrant, 2001). Previous reports indicate that increased concentrations of wheat shorts in diets based on casein increased the endogenous losses and linearly reduced the SID of most indispensable AA (Libao-Mercado et al., 2006).

The AID and SID of Lys in wheat middlings determined in this experiment were less than values observed for all other indispensable AA. This observation is consistent with results observed for the SID of AA in wheat DDGS (Nyachoti et al., 2005). In contrast, the AID and SID of Lys in wheat grain is close to that of other indispensable AA (Stein et al., 2001; Pedersen et al., 2007; NRC, 2012; Cervantes-Pahm et al., 2014). The low AID and SID that were observed for wheat middlings in this experiment is, therefore, most likely a result of heat damage in processing of the grain because heat damage will reduce the digestibility of Lys more than that of other AA (Fontaine et al., 2007; Gonzalez-Vega et al., 2011; Almeida et al., 2013). Feed ingredients that are not heat damaged usually have a greater SID of Lys than of Thr because the basal endogenous loss of Thr is much greater than of Lys (Stein et al., 1999). As a consequence, if a feed ingredient has a SID of Lys that is less than that of Thr, it is likely that this ingredient has been heat damaged (Maison and Stein, 2014). The observation that the SID of Lys for wheat middlings that were determined in this experiment are less than the SID for Thr further indicates that the wheat middlings used in this experiment was heat damaged during drying or processing. The fact that a reduced SID of Lys compared with the SID of Thr was observed not only for the average values for SID of Lys and Thr, but also for each individual source of wheat middlings, indicates that there are manufacturing procedures generally used in the processing of wheat that results in heat damage of the coproducts and the relatively low SID of AA in wheat middlings, therefore, appears to be a characteristic of this ingredient that is a result of the production process.

In conclusion, the concentration of AA in wheat middlings and red dog was not different, but the AID and SID of CP and AA were less in wheat middlings than in red dog. The values for AID and SID of CP and AA of wheat middlings were less than values previously reported. It is likely that the concentration of fiber and heat damage during processing of wheat middlings may contribute to the relative low digestibility of AA in this ingredient. As a consequence, diets fed to pigs that contain wheat middlings need to also contain crystalline AA or other ingredients that can complement the low digestibility of AA in wheat middlings to produce a diet that is balanced in digestible AA.

Exp. 2. Energy and Fiber Digestibility

Physical Characteristics of Wheat Middlings and Red Dog. The bulk density of the sources of wheat middlings ranged from 289 to 333 g/L, which concurs with the values reported by Cromwell et al. (2000). However, the bulk density of the red dog was 498 g/L. 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 holding capacity was 3.11 ± 0.2 g/g in wheat middlings and 1.83 g/g in red dog.

Digestibility of GE, DM, OM, NDF, and ADF in Diets and Ingredients. There were not differences in GE intake, GE in feces, or GE in urine among diets containing the 10 sources of wheat middlings or between the diets containing wheat middlings or red dog (Table 10). The ATTD of GE, DM, OM, NDF, and ADF was 80.0, 81.3, 83.3, 53.9, and 48.7% in diets containing wheat middlings, but 85.4, 87.0, 89.0, 61.4, and 64.9% , respectively, in diets containing red dog. Differences were observed ($P < 0.05$) among diets containing wheat middlings for the ATTD of GE, DM, OM, NDF, and ADF. The ATTD of OM, NDF, and ADF was greater ($P < 0.05$) in diets containing red dog compared with diets containing wheat middlings. The ATTD of DM tended to be greater ($P = 0.059$) in red dog than in wheat middlings. However, there were no differences in ATTD of GE of diets containing wheat middlings compared with the diet containing red dog.

The ATTD of GE, DM, OM, NDF, and ADF in wheat middlings was 67.2, 71.2., 72.9., 40.7, and 28.0%, respectively; and differences ($P < 0.05$) among sources were (Table 11). The ATTD of GE and DM values obtained in this experiment are greater than reported by Nortey et al. (2008). The average ATTD of NDF is in agreement with reported values, but the ATTD of ADF obtained in this experiment was greater than previously reported (Jaworski, 2016).

The concentration of DE in the wheat middlings sources ranged from 2,352 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 DM-basis among the wheat middlings sources ranged from 2,637 to 3,185 kcal/kg, whereas the concentration of ME on DM-basis varied between 2,546 to 3,056 kcal/kg. The values of DE on DM-basis observed in this experiment are very close to the value reported by Nortey et al. (2008).

The ATTD of GE, DM, OM, NDF, and ADF in red dog was 79.3, 82.9, 86.6, 29.2 and 22.6%, respectively. The ATTD of GE observed in this experiment was less than reported for red dog from China (Huang et al., 2012). The ATTD of GE, DM, OM, NDF and ADF were greater ($P < 0.05$) in red dog, compared with the average for the 10 sources of wheat middlings. The concentrations of DE and DE on DM-basis in red dog were 3,058 and 3,418 kcal/kg, respectively; and the concentrations of ME and ME on DM-basis in red dog were 2,952 and 3,300 kcal/kg, respectively. These value are less than reported by Huang et al. (2012). However, the concentrations of DE and ME (as is and DM) were greater ($P < 0.05$) in red dog than in the sources of wheat middlings.

Equations to predict the concentrations of DE and ME in wheat middlings are presented in Table 12. The models had r^2 values from 0.95 to 0.53. The model that included all the nutrients as explanatory variables had the greatest r^2, but was not significant ($P = 0.316$). The model that included AEE, ADF, NDF, lignin and starch was significant ($P = 0.02$) and had $r^2 = 0.927$.

The r^2 values for the models to predict the ME in wheat middlings ranged from 0.936 to 0.614. The model that included GE, ADF, NDF, lignin and starch, had an $r^2 = 0.89$ and was significant ($P = 0.042$). The most reduced model was significant ($P = 0.007$) and included starch as the only explanatory variable, however the r^2 was 0.614.

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Table 1. Proximate analysis and amino acids in the 10 sources of wheat middlings and red dog (as-fed basis)

Item, %	Wheat middlings sources										
	1	2	3	4	5	6	7	8	9	10	Mean
GE, kcal/kg	3,838	3,871	4,033	3,900	4,046	3,996	4,029	4,012	4,045	4,015	3,979
DM	86.51	87.80	89.44	89.98	89.20	89.13	88.74	88.01	89.55	89.32	88.77
CP	17.75	18.39	17.21	18.83	18.13	17.00	17.10	17.98	17.30	17.01	17.67
AEE[1]	2.33	4.60	4.02	3.31	4.98	3.96	4.04	4.25	4.50	4.71	4.07
ADF	11.01	9.99	9.44	10.77	12.22	10.74	10.24	10.27	11.52	11.87	10.81
NDF	34.35	33.08	33.72	35.61	40.28	34.30	33.62	34.04	37.71	38.4	35.51
Lignin	2.99	2.69	2.66	3.35	4.32	2.67	2.59	3.12	2.85	2.99	3.02
Ash	4.90	6.67	4.94	7.08	5.20	5.01	4.88	5.01	5.14	5.78	5.46
Ca	0.08	0.36	0.07	0.73	0.08	0.10	0.14	0.08	0.07	0.09	0.18
P	1.04	1.22	1.18	1.12	1.22	1.11	1.13	1.10	1.23	1.32	1.17
Indispensable, AA											
Arg	1.07	1.14	1.10	1.11	1.11	1.05	1.04	1.08	1.08	1.10	1.09
His	0.45	0.45	0.44	0.45	0.44	0.45	0.45	0.45	0.44	0.45	0.45
Ile	0.57	0.58	0.55	0.58	0.56	0.52	0.52	0.57	0.54	0.55	0.55
Leu	1.07	1.08	1.04	1.08	1.04	1.06	1.07	1.08	1.02	1.01	1.06
Lys	0.69	0.73	0.69	0.72	0.72	0.74	0.73	0.71	0.70	0.72	0.72
Met	0.26	0.24	0.25	0.24	0.25	0.24	0.23	0.26	0.25	0.26	0.25
Phe	0.68	0.67	0.65	0.67	0.66	0.65	0.66	0.68	0.64	0.63	0.66
Thr	0.53	0.54	0.52	0.55	0.53	0.53	0.53	0.54	0.52	0.52	0.53

Trp	0.2	0.14	0.15	0.15	0.16	0.14	0.14	0.16	0.18	0.15	0.16
Val	0.81	0.82	0.79	0.83	0.79	0.80	0.80	0.8	0.78	0.79	0.80
Dispensable, AA%											
Ala	0.77	0.80	0.76	0.82	0.78	0.80	0.79	0.79	0.77	0.78	0.79
Asp	1.12	1.22	1.15	1.20	1.20	1.15	1.13	1.17	1.14	1.20	1.17
Cys	0.32	0.31	0.33	0.31	0.32	0.31	0.30	0.33	0.32	0.33	0.32
Glu	3.14	3.05	3.09	3.08	2.94	2.85	2.82	3.36	3.04	2.89	3.03
Gly	0.85	0.86	0.84	0.9	0.84	0.84	0.82	0.87	0.85	0.88	0.86
Pro	1.00	0.97	1.00	0.99	0.90	0.94	0.91	1.07	0.95	0.92	0.97
Ser	0.60	0.59	0.60	0.61	0.58	0.59	0.59	0.62	0.60	0.58	0.60
Tyr	0.42	0.42	0.41	0.42	0.40	0.40	0.40	0.42	0.41	0.38	0.41
Total AA	14.61	14.70	14.42	14.78	14.30	14.13	14.01	15.03	14.30	14.21	14.45
Lys:CP ratio	3.89	3.97	4.01	3.82	3.97	4.35	4.27	3.95	4.05	4.23	4.05

[1] AEE = acid hydrolyzed ether extract.

Table 2. Ingredient composition of experimental diets, Exp. 1

Ingredient, %	Wheat co-product[1]	N-free diet
Wheat co-product	45.00	-
Sucrose	15.00	20.00
Corn starch	33.20	68.35
Soybean oil	4.00	4.00
Solka floc[2]	-	4.00
Limestone	1.60	0.45
Dicalcium phosphate	0.10	1.60
Magnesium oxide	-	0.10
Potassium carbonate	-	0.40
Sodium chloride	0.40	0.40
Vitamin mineral premix[3]	0.30	0.30
Chromic oxide	0.40	0.40

[1] Ten diets using 10 different sources of wheat middlings and one diet using red dog were formulated.

[2] Fiber Sales and Development Corp., Urbana, OH.

[3] The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrocloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and niacotinic acid,

44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

Table 3. Analyzed composition of experimental diets (as-feed basis), Exp. 1

Item, %	Wheat middlings, source										Red dog	N-free
	1	2	3	4	5	6	7	8	9	10		
DM	92.35	92.52	93.13	93.89	92.94	92.9	93	92.5	93.46	92.65	92.52	93.24
CP	8.07	8.58	7.66	8.4	8.39	7.64	7.94	8.34	7.66	7.63	8.12	0.24
Indispensable, AA												
Arg	0.48	0.51	0.47	0.51	0.51	0.45	0.47	0.49	0.48	0.49	0.38	0.01
His	0.21	0.21	0.2	0.21	0.21	0.21	0.21	0.21	0.2	0.21	0.18	-
Ile	0.27	0.27	0.26	0.28	0.26	0.24	0.25	0.27	0.25	0.26	0.27	0.01
Leu	0.5	0.5	0.47	0.52	0.49	0.49	0.5	0.49	0.48	0.48	0.49	0.02
Lys	0.32	0.33	0.32	0.36	0.34	0.33	0.34	0.33	0.33	0.34	0.29	0.02
Met	0.11	0.11	0.11	0.11	0.12	0.11	0.12	0.11	0.11	0.11	0.17	-
Phe	0.32	0.31	0.3	0.32	0.31	0.3	0.31	0.31	0.3	0.29	0.32	0.01
Thr	0.25	0.25	0.23	0.26	0.25	0.24	0.25	0.25	0.24	0.25	0.53	0.01
Trp	0.1	0.07	0.08	0.08	0.08	0.08	0.07	0.08	0.09	0.08	0.08	< 0.02

Val	0.37	0.38	0.35	0.39	0.37	0.36	0.37	0.36	0.36	0.36	0.34	0.01
Dispensable, AA%												
Ala	0.36	0.38	0.35	0.39	0.37	0.36	0.37	0.36	0.35	0.36	0.3	0.01
Asp	0.53	0.56	0.51	0.57	0.57	0.53	0.54	0.54	0.53	0.56	0.48	0.02
Cys	0.15	0.15	0.15	0.15	0.14	0.14	0.14	0.15	0.15	0.15	0.12	0
Glu	1.56	1.47	1.44	1.56	1.45	1.36	1.39	1.58	1.46	1.36	1.67	0.05
Gly	0.4	0.42	0.38	0.43	0.41	0.38	0.39	0.4	0.39	0.4	0.34	0.01
Pro	0.48	0.47	0.44	0.49	0.45	0.45	0.45	0.47	0.44	0.45	0.53	0.01
Ser	0.3	0.29	0.28	0.31	0.29	0.28	0.29	0.3	0.29	0.28	0.28	0.01
Tyr	0.18	0.19	0.17	0.19	0.18	0.15	0.17	0.18	0.17	0.17	0.19	0.01
Total AA	6.89	6.87	6.51	7.13	6.8	6.46	6.63	6.88	6.62	6.6	6.96	0.21

Table 4. Composition of amino acid mixture[1], Exp. 1

Amino acid	%
Gly	57.90
L-Lys HCL	13.51
DL-Met	4.44
L-Thr	5.79
L-Trp	1.35
L-Ile	4.25
L-Val	4.83
L-His	2.12
L-Phe	5.79
Total	100.00

[1] One hundred fifty grams of this mixture was fed daily to each pig during the adaptation periods.

Table 5. Ingredient composition of the corn-soybean diet and diets containing red dog or wheat middlings, Exp. 2

Ingredient, %	Diet	
	Corn-soybean meal	Wheat middlings or red dog[1]
Corn	65.00	39.00
Soybean meal	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[2]	0.30	0.30

[1] Ten diets using 10 different sources of wheat middlings and one diet using red dog were formulated.

[2] The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrocloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and niacotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

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Table 6. Analyzed composition (as-fed basis) of the corn-soybean diet and diets containing red dog or wheat middlings, Exp. 2

Item	Basal diet	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
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
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
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
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.

Table 7. Analyzed composition (as fed basis) and physical characteristics of corn, soybean meal, red dog and the 10 sources of wheat middlings that were used in Exp. 2

	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	3,978	91.30
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	88.77	1.01
CP	-	-	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	0.87
ADF	4.63	7.71	3.37	11.01	9.99	9.44	10.77	12.22	10.74	10.24	10.27	11.52	11.87	10.80	2.39
NDF	13.61	6.04	11.81	34.35	33.08	33.72	35.61	40.28	34.30	33.62	34.04	37.71	38.4	35.51	7.51
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	0.86
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	0.80
Ca	-	-	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	-	-	0.48	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

Glucose	0.26	1.06	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	1.55	0.08	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	-	7.37	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	0.29	0.21	0.27	0.56	0.39	0.30	0.33	0.3	0.34	0.35	0.41	0.35	0.40	0.37	0.08
Stachyose	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Raffinose	0.15	1.58	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	93.55
WHC[3], 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

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

[2] AEE = acid hydrolyzed ether extract.

[3] WHC = Water holding capacity.

Table 8. Apparent ileal digestibility of crude protein and amino acids in wheat middlings and red dog[1], Exp. 1

Item, %	Wheat middlings source												Red dog	Wheat middlings[2]			Wheat middlings vs. red dog[3]	
	1	2	3	4	5	6	7	8	9	10	Mean	SD		SEM	*P*-value	LSD	SEM	P-value
CP	36.9	42.5	25.8	31.6	35.8	27.2	36.7	32.5	26.3	18.2	31.4	7.1	46.9	4.92	<0.019	13.02	4.29	0.001
Indispensable, AA																		
Arg	60.3	63.3	60.1	60.3	65.5	57.1	61.1	58.9	63.3	56.8	60.7	2.8	60.8	3.76	0.816	10.26	3.80	0.959
His	72.7	67.4	67.7	67.6	68.2	65.5	67.2	70.7	65.1	65.5	67.7	2.4	63.6	1.70	0.128	4.66	1.57	0.017
Ile	62.9	59.8	57.9	62.3	60.1	51.8	53.3	59.8	54.8	51.7	57.5	4.2	72.5	2.01	<0.001	5.66	2.03	<0.001
Leu	67.0	62.9	61.0	64.8	63.4	58.6	60.5	63.8	59.7	56.4	61.8	3.2	73.5	1.92	0.015	5.27	1.84	<0.001
Lys	23.2	37.4	27.3	36.2	31.7	30.7	30.4	32.8	31.1	22.0	30.3	5.0	54.2	3.56	0.059	9.55	3.09	<0.001
Met	69.1	66.4	67.0	66.5	70.6	64.3	68.0	67.2	65.2	64.1	66.8	2.0	86.1	1.31	0.040	3.60	1.24	<0.001

Phe	68.5	63.4	62.1	65.0	64.4	58.7	61.0	65.2	60.6	56.4	62.5	3.5	75.5	1.86	0.002	5.09	1.78	<0.001
Thr	46.5	42.3	39.4	43.5	42.3	31.2	36.0	39.7	37.1	33.6	39.2	4.7	76.1	2.57	0.002	6.99	2.44	<0.001
Trp	71.7	59.5	61.4	61.5	61.4	58.3	52.5	60.0	62.6	53.1	60.2	5.3	78.2	2.06	<0.001	5.64	1.93	<0.001
Val	54.8	50.7	46.2	50.3	49.8	42.4	44.9	48.2	46.7	38.7	47.3	4.6	53.7	2.41	0.001	6.50	2.41	0.010
Dispensable, AA																		
Ala	38.6	41.4	33.6	41.3	40.6	32.6	36.2	34.3	35.7	26.4	36.1	4.7	53.1	3.55	0.050	9.24	3.34	<0.001
Asp	55.1	54.7	50.2	53.6	54.7	47.7	49.3	53.1	51.3	47.1	51.7	3.0	59.8	2.16	0.059	5.90	2.06	0.003
Cys	63.2	59.9	64.0	60.5	57.6	54.4	55.7	62.3	60.0	56.0	59.3	3.3	39.8	1.79	0.001	4.90	7.90	<0.001
Glu	78.3	75.4	75.8	77.1	75.7	72.2	72.9	77.7	74.5	69.9	74.9	2.6	85.9	1.28	<0.001	3.50	1.18	<0.001
Ser	59.7	54.5	53.5	55.3	53.8	47.2	51.2	55.3	49.2	43.1	52.3	4.7	54.8	2.70	0.007	7.40	2.48	0.290
Tyr	61.4	58.0	53.5	60.0	57.8	45.8	50.2	57.3	51.3	47.8	54.3	5.4	72.3	2.47	<0.001	6.76	2.39	<0.001
Total AA	62.2	58.8	58.1	60.9	61.5	53.1	55.9	59.7	56.4	51.6	57.9	3.6	71.8	1.92	0.002	5.26	1.88	<0.001

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[1] Values are means for 8 observations per treatment.

[2] Comparison of the 10 wheat middlings sources.

[3] Comparison of wheat middlings and red dog.

Table 9. Standardized ileal digestibility of crude protein and amino acids in wheat middlings and red dog[1,2], Exp. 1

Item, %	Wheat middlings source												Red dog	Wheat middlings[3]			Wheat middlings vs. red dog[4]	
	1	2	3	4	5	6	7	8	9	10	Mean	SD		SEM	P-value	LSD	SEM	P-value
CP	62.2	67.1	61.1	57.0	64.6	58.7	67.2	64.2	58.1	51.5	61.2	4.9	78.5	4.52	0.258	12.36	4.52	<0.001
Indispensable AA																		
Arg	78.9	84.0	82.0	80.6	85.0	80.5	82.9	77.1	84.4	78.3	81.4	2.7	87.8	3.94	0.887	10.68	3.91	0.124
His	81.6	77.2	78.1	77.7	78.1	75.3	77.0	80.5	75.7	75.4	77.7	2.1	75.1	1.64	0.143	4.51	1.57	0.126
Ile	72.4	71.4	70.0	73.9	72.4	64.8	65.9	71.1	67.7	63.9	69.4	3.5	84.1	2.05	0.050	5.64	2.03	<0.001
Leu	77.8	73.5	72.3	75.3	74.3	69.4	71.1	74.5	71.0	67.7	72.7	3.0	84.4	1.90	0.050	5.22	1.84	<0.001
Lys	38.3	54.0	44.1	51.1	46.9	44.3	46.3	49.3	47.4	37.4	45.9	5.2	72.3	3.59	0.040	9.67	3.18	<0.001
Met	75.4	73.2	74.0	73.5	77.0	71.1	74.3	73.9	72.1	71.0	73.6	1.9	90.6	1.28	0.071	3.52	1.24	<0.001

Phe	76.6	73.6	72.8	75.3	74.8	69.2	71.3	75.3	71.5	67.6	72.8	2.9	85.4	1.83	0.016	5.06	1.78	<0.001
Thr	67.3	65.7	62.9	67.0	65.9	55.8	59.7	63.2	62.2	57.0	62.7	4.1	87.3	2.64	0.022	7.25	2.56	<0.001
Trp	78.3	71.3	71.9	72.2	72.0	68.6	64.5	70.2	72.0	63.6	70.5	4.2	88.5	2.02	0.002	5.58	1.93	<0.001
Val	68.4	66.9	64.0	66.7	66.7	59.5	61.6	65.2	64.4	59.2	64.3	3.2	71.9	2.42	0.014	6.65	2.41	0.003
Dispensable AA																		
Ala	54.9	59.9	54.7	60.3	60.6	48.2	55.9	53.3	53.9	46.1	54.8	4.9	77.4	3.70	0.090	10.14	3.74	<0.001
Asp	68.3	69.6	66.2	68.5	69.0	63.5	64.2	68.4	64.0	62.2	66.4	2.7	77.1	2.34	0.217	6.44	2.30	<0.001
Cys	76.2	73.8	78.1	74.8	72.7	69.4	70.8	76.3	74.3	70.1	73.7	2.9	57.3	1.73	0.009	4.77	1.90	<0.001
Glu	83.9	82.2	82.8	83.7	82.7	79.6	80.1	84.0	81.5	77.4	81.8	2.2	91.9	1.24	0.005	3.42	1.18	<0.001
Ser	77.0	73.8	74.5	73.8	74.9	67.0	71.4	74.1	72.2	66.7	72.5	3.4	74.9	2.19	0.033	6.01	2.03	0.263
Tyr	72.5	71.0	68.2	73.5	71.8	62.3	64.8	70.9	66.4	62.7	68.4	4.1	85.5	2.44	0.006	6.73	2.40	<0.001
Total AA	73.4	73.1	72.1	73.7	72.0	67.3	69.6	73.0	70.1	65.2	71.0	2.9	84.4	2.08	0.066	5.73	2.03	<0.001

[1] Values are means for 8 observations per treatment.

[2] Values for standardized ileal digestibility were calculated by correcting apparent ileal digestibility values for basal endogenous losses. Basal endogenous losses were determine using pig fed N-free diet as (g/kg DMI) CP, 27.86; Arg, 1.11; His, 0.22 Ile, 0.34; Leu, 0.57; Lys, 0.58; Met, 0.08; Phe, 0.34; Thr, 0.34, Trp, 0.0.9; Val 0.67; Ala, 0.79; Asp, 0.89; Cys, 0.23; Glu, 1.09; Ser, 0.61; Tyr, 0.27.

[3] Comparison of the 10 sources of wheat middlings.

[4] Comparison of wheat middlings and red dog.

Table 10. Apparent total tract digestibility (ATTD, %) of GE, DM, OM, NDF, and ADF, and concentration of DE and ME in the basal corn soybean meal diet and in diets containing wheat middlings or red dog[1], Exp. 2

Item	Basal	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	SD	SEM	*P*-value	LSD	
GE intake, kcal/d	8,588	9,020	8,952	8,998	9,253	8,986	8,760	9,150	9,111	9,071	8,913	9,003	9,020	135	31.6	0.362	362	0.449
GE in feces, kcal/d	905	1,290	1,695	1,717	1,762	1,803	1,884	1,702	1,734	1,664	1,752	1,716	1,743	62.9	58.13	0.371	160	0.865
GE in urine, kcal/d	430.1	367.7	333.6	355.9	357.5	335.3	340	331.9	361.1	297.3	310.5	361	338	21.7	24.45	0.755	72.09	0.498
ATTD of GE, %	89.4	85.4	80.8	80.6	79.9	79.8	78.1	81.3	80.6	81.5	80.3	79.6	80.0	1.0	0.378	<0.001	1.03	0.82
ATTD of DM, %	90.5	87	81.1	81.4	82.4	80.1	80.4	81.3	82.5	81.8	81.9	80.2	81.3	0.9	0.36	<0.001	0.992	0.059

ATTD of OM, %	91.9	89.02	83.1	83.4	84	82.2	82.5	83.3	84.3	83.8	84	82.2	83.3	0.8	0.32	<0.001	0.990	0.0318
ATTD of NDF, %	78.1	61.4	50.9	50.9	63.4	48.4	50.1	51	56.4	56.1	56	56.1	53.9	4.5	1.15	<0.001	3.19	0.002
ATTD of ADF, %	82.8	64.9	47.09	50.1	48.18	42.05	49.19	50.65	49.77	52.32	52.14	45.2	48.7	3.2	1.35	<0.001	3.72	0.022
DE, kcal/kg	3,465	3,284	3,133	3,094	3,121	3,088	3,006	3,200	3,153	3,183	3,156	3,114	3,125	55.2	14.74	<0.001	40.44	0.639
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	53.8	19.3	<0.001	53.11	0.8879

[1] Values are means of 8 observations per treatment.

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

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

Table 11. Apparent total tract digestibility (ATTD) of energy, DM, OM, NDF, and ADF, and concentration of DE and ME in wheat middlings and red dog[1], Exp. 2

Item	Wheat middlings source												Red dog	Wheat middlings			Red dog vs. Wheat middlings	
	1	2	3	4	5	6	7	8	9	10	Mean	SD		SEM	*P*-value	LSD	SEM	*P*-value
ATTD of GE, %	68.6	68.1	66.4	66.0	61.9	69.7	68.1	70.3	67.2	65.5	67.2	2.4	79.3	0.911	0.005	2.50	1.04	<0.001
ATTD of DM, %	70.4	71.3	73.4	68.7	69.3	71.3	73.6	72.2	72.4	68.9	71.2	1.8	82.9	0.81	<0.001	2.22	0.875	<0.001
ATTD of OM, %	72.3	72.8	74.6	70.1	70.9	73.0	75.6	74.1	74.9	70.5	72.9	1.9	86.6	0.79	<0.001	2.17	0.888	<0.001
ATTD of NDF, %	35.5	34.0	56.6	31.5	35.5	34.8	44.4	43.9	44.1	46.7	40.7	7.8	29.2	1.17	<0.001	4.81	1.910	<0.001
ATTD of ADF, %	25.0	29.5	22.7	15.6	31.8	32.1	27.7	37.2	34.6	24.0	28.0	6.4	33.6	2.14	<0.001	5.87	2.335	0.0271
DE, kcal/kg	2,674	2,575	2,644	2,561	2,352	2,844	2,724	2,800	2,733	2,626	2,653	139	3,058	40.4	<0.001	111.3	45.4	<0.001

DE, kcal/kg DM-basis	3,103	2,933	2,956	2,846	2,637	3,185	3,070	3,182	3,052	2,932	2,990	167	3,418	45.5	<0.001	125.2	51.1	<0.001
ME, kcal/kg	2,600	2,472	2,570	2,482	2,272	2,729	2,632	2,751	2,630	2,537	2,568	139	2,952	49.0	<0.001	134.8	53.2	<0.001
ME, kcal/kg, DM-basis	3,017	2,816	2,873	2,758	2,546	3,056	2,966	3,125	2,937	2,833	2,893	167	3,300	55.2	<0.001	151.7	59.86	<0.001

[1] Values are means of 8 observations per treatment.

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

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

Table 12. Prediction equations for DE and ME in wheat middlings[1], Exp. 2

Equation	r^2	*P* -value
DE		
$Y = -5{,}083.9 + (1.56 \times GE) - (52.30 \times PC) + (1.50 \times AEE) + (288.25 \times ADF) - (64.62 \times NDF) - (81.57 \times Lignin) + (133.53 \times Ash) + (59.39 \times Starch)$	0.953	0.453
$Y = -4{,}517.33 + (1.33 \times GE) + (4.17 \times AEE) + (198.42 \times ADF) - (50.45 \times NDF) - (147.25 \times Lignin) + (81.19 \times Ash) + (49.68 \times Starch)$	0.941	0.179

$Y = 702.40 + (0.33 \times \mathrm{GE}) + (42.89 \times \mathrm{AEE}) + (197.54 \times \mathrm{ADF}) - (58.71 \times \mathrm{NDF}) - (129.57 \times \mathrm{Lignin}) + (43.93 \times \mathrm{Starch})$	0.932	0.070
$Y = 1{,}537.2 - (69.10 \times \mathrm{AEE}) + (211.75 \times \mathrm{ADF}) - (55.97 \times \mathrm{NDF}) - (131.10 \times \mathrm{Lignin}) + (54.71 \times \mathrm{Starch})$	0.927	0.02
$Y = 2{,}023.8 + (136.17 \times \mathrm{ADF}) - (26.82 \times \mathrm{NDF}) - (163.07 \times \mathrm{Lignin}) + (41.2 \times \mathrm{Starch})$	0.870	0.019
$Y = 1{,}476.9 + (91.37 \times \mathrm{ADF}) - (190.9 \times \mathrm{Lignin}) + (46.27 \times \mathrm{Starch})$	0.851	0.006
$Y = 2{,}783.5 - (136.3 \times \mathrm{Lignin}) + (29.64 \times \mathrm{Starch})$	0.735	0.009
$Y = 1{,}949.9 + (45.8 \times \mathrm{Starch})$	0.579	0.010
ME		
$Y = -9{,}131.9 + (2.37 \times \mathrm{GE}) - (51.7 \times \mathrm{PC}) - (39.38 \times \mathrm{AEE}) + (212.4 \times \mathrm{ADF}) - (57.62 \times \mathrm{NDF}) - 66.03 \times \mathrm{Lignin}) + (186.47 \times \mathrm{Ash}) + (61.93 \times \mathrm{Starch})$	0.936	0.516
$Y = -6.825.4 + (1.81 \times \mathrm{GE}) - (49.62 \times \mathrm{PC}) + (230.1 \times \mathrm{ADF}) - (62.4 \times \mathrm{NDF}) - (58.81 \times \mathrm{Lignin}) + (155.6 \times \mathrm{Ash}) + (67.89 \times \mathrm{Starch})$	0.932	0.217
$Y = -6{,}434.9 + (1.61 \times \mathrm{GE}) + (200.6 \times \mathrm{ADF}) - (48.66 \times \mathrm{NDF}) - (121.76 \times \mathrm{Lignin}) + (107.79 \times \mathrm{Ash}) + (58.28 \times \mathrm{Starch})$	0.925	0.081

$Y = – 379.15 + (0.69 \times GE) + (160.73 \times ADF) – (54.67 \times NDF) – (105.5 \times Lignin) + (33.57 \times Starch)$	0.891	0.042
$Y = – 112.48 + (0.34 \times GE) + (78.55 \times ADF) – (161.55 \times Lignin) + (47.25 \times Starch)$	0.836	0.033
$Y = 1{,}229.7 + (87.41 \times ADF) – (160.87 \times Lignin) + (50.46 \times Starch)$	0.816	0.012
$Y = 2{,}479 - (108.66 \times Lignin) + (34.55 \times Starch)$	0.712	0.013
$Y = 1{,}815.2 + (47.43 \times Starch)$	0.614	0.007

[1] Units for GE are kcal/kg DM; units for nutrients are % of DM; AEE = acid hydrolyzed ether extract.