The ileal digestibility of most amino acids is greater in red dog than in wheat middlings when fed to growing pigs[1]

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ABSTRACT: The objective of this experiment was to determine the apparent ileal digestibility (AID) and the standardized ileal digestibility (SID) of CP and AA in 10 sources of wheat middlings and in 1 source of red dog. Ten diets that each contained 1 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. Chromic oxide (0.4%) was added to all diets as an indigestible marker. 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 diets 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. Results indicated that the AID of CP in wheat middlings was 31.1 ± 6.9%, but the AID of CP in red dog (47.0%) was greater ($P < 0.05$) than the average AID of CP for wheat middlings. The AID of indispensable AA in wheat middlings ranged from 30.1 ± 5.4% for Lys to 67.7 ± 2.2% for His, and the AID of indispensable AA in red dog ranged from 53.7% in Val to 86.2% for Met. The average SID of CP in wheat middlings was 61.5 ± 5.1%, and there were no differences among the 10 sources of wheat middlings, but 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 ± 1.8%) and the SID of Ala (54.8 ± 4.9%) tended ($P = 0.071$ and $P = 0.090$, 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. In conclusion, wheat middlings and red dog contain approximately the same quantities of AA, but the AID and SID of CP and most AA in red dog are greater than in wheat middlings.

Key words: amino acid digestibility, pigs, red dog, wheat middlings

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INTRODUCTION

Wheat is the third most important crop (after maize and soybeans) produced in the U.S. if measured based on acres harvested (Bond and Liefert, 2016). Most wheat is used for human consumption and between 70% and 75% of the wheat grain becomes flour, whereas the 25% to 30% of the wheat grains that is 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; AAFCO, 2000). Wheat middlings consist of particles of wheat bran, wheat germ, wheat flour, and fractions of wheat shorts (AAFCO, 2000;

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Table 1. Analyzed composition of the 10 sources of wheat middlings and red dog (as-fed basis)

	Wheat middlings source												
Item	1	2	3	4	5	6	7	8	9	10	Mean	SD	Red dog
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	78	3,801
DM, %	86.51	87.80	89.44	89.98	89.20	89.13	88.74	88.01	89.55	89.32	88.77	1.04	89.47
CP, %	17.75	18.39	17.21	18.83	18.13	17.00	17.10	17.98	17.30	17.01	17.67	0.64	17.00
AEE[1], %	2.33	4.60	4.02	3.31	4.98	3.96	4.04	4.25	4.50	4.71	4.07	0.77	2.50
ADF, %	11.01	9.99	9.44	10.77	12.22	10.74	10.24	10.27	11.52	11.87	10.81	0.87	3.37
NDF, %	34.35	33.08	33.72	35.61	40.28	34.30	33.62	34.04	37.71	38.4	35.51	2.44	11.81
Lignin, %	2.99	2.69	2.66	3.35	4.32	2.67	2.59	3.12	2.85	2.99	3.02	0.51	0.67
Ash, %	4.90	6.67	4.94	7.08	5.20	5.01	4.88	5.01	5.14	5.78	5.46	0.79	6.37
Ca, %	0.08	0.36	0.07	0.73	0.08	0.10	0.14	0.08	0.07	0.09	0.18	0.21	0.87
P, %	1.04	1.22	1.18	1.12	1.22	1.11	1.13	1.10	1.23	1.32	1.17	0.08	0.48
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	0.03	0.84
His	0.45	0.45	0.44	0.45	0.44	0.45	0.45	0.45	0.44	0.45	0.45	–	0.36
Ile	0.57	0.58	0.55	0.58	0.56	0.52	0.52	0.57	0.54	0.55	0.55	0.02	0.56
Leu	1.07	1.08	1.04	1.08	1.04	1.06	1.07	1.08	1.02	1.01	1.06	0.03	1.03
Lys	0.69	0.73	0.69	0.72	0.72	0.74	0.73	0.71	0.70	0.72	0.72	0.02	0.63
Met	0.26	0.24	0.25	0.24	0.25	0.24	0.23	0.26	0.25	0.26	0.25	0.01	0.37
Phe	0.68	0.67	0.65	0.67	0.66	0.65	0.66	0.68	0.64	0.63	0.66	0.02	0.67
Thr	0.53	0.54	0.52	0.55	0.53	0.53	0.53	0.54	0.52	0.52	0.53	0.01	0.55
Trp	0.2	0.14	0.15	0.15	0.16	0.14	0.14	0.16	0.18	0.15	0.16	0.02	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	0.02	0.70
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	0.02	0.63
Asp	1.12	1.22	1.15	1.20	1.20	1.15	1.13	1.17	1.14	1.20	1.17	0.03	0.98
Cys	0.32	0.31	0.33	0.31	0.32	0.31	0.30	0.33	0.32	0.33	0.32	0.01	0.29
Glu	3.14	3.05	3.09	3.08	2.94	2.85	2.82	3.36	3.04	2.89	3.03	0.16	3.58
Gly	0.85	0.86	0.84	0.9	0.84	0.84	0.82	0.87	0.85	0.88	0.86	0.02	0.69
Pro	1.00	0.97	1.00	0.99	0.90	0.94	0.91	1.07	0.95	0.92	0.97	0.05	1.13
Ser	0.60	0.59	0.60	0.61	0.58	0.59	0.59	0.62	0.60	0.58	0.60	0.01	0.58
Tyr	0.42	0.42	0.41	0.42	0.40	0.40	0.40	0.42	0.41	0.38	0.41	0.01	0.43
Total AA	14.61	14.70	14.42	14.78	14.30	14.13	14.01	15.03	14.30	14.21	14.45	0.32	14.25
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	0.17	3.71

[1] AEE = acid hydrolyzed ether extract.

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 CP and AA in some wheat coproducts produced in Canada and China has been reported (Nyachoti et al., 2005; Nortey et al., 2008; Huang et al., 2012), but there is limited information about the nutritional value of wheat middlings and red dog produced in the U.S. Therefore, the objective of this experiment was to determine the apparent ileal digestibility (**AID**) and the standardized ileal digestibility (**SID**) of CP and AA in 10 sources of wheat middlings and in 1 source of red dog.

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, or PA (Table 1).

Animals and Housing

Twelve pigs that were the offspring of Line 359 boars mated to Camborough 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. Pigs were 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 1 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 met or 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 (i.e., 197 kcal/kg BW$^{0.60}$; 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, 50 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 subsample 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, 2007), CP by combustion (Method 990.03; AOAC, 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, 2007). Diets and ileal digesta samples were also analyzed for Cr (Method 990.09; AOAC, 2007). Ingredients were analyzed in duplicate for ash (Method 942.05; AOAC, 2007), and GE using an isoperibol bomb calorimeter (Model 6300; Parr Instruments, Moline, IL) with benzoic acid serving as the standard for calibration. Acid hydrolyzed ether extract was analyzed in red dog and the 10 sources of wheat middlings using an ANKOM HCL hydrolysis system and an ANKOM XT15 fat extractor (method AM 5-04; AOAC, 2007). 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, 2007).

Table 2. Ingredient composition of experimental diets

Ingredient, %	Wheat coproduct[1]	N-free diet
Wheat coproduct	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] 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-alpha 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 dihydriodide; 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.

Calculations and Statistical Analysis

Values for AID and SID of AA in each diet were calculated (Stein et al., 2007) and because the wheat coproducts 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

Table 3. Analyzed composition of experimental diets (as-fed basis)

	Wheat middlings, source											
Item, %	1	2	3	4	5	6	7	8	9	10	Red dog	N-free
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

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 using PROC GLM of SAS. The 10 sources of wheat middlings were compared using ANOVA with wheat coproduct, period, and pig 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 described as a tendency if $0.05 < P < 0.10$.

Table 4. Composition of amino acid mixture[1]

Amino acid	%
Gly	57.92
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 grams of this mixture was fed daily to each pig during the adaptation periods.

RESULTS AND DISCUSSION

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. 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. The concentration of Lys in wheat middlings that was observed in this experiment is greater than previously reported (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) compared with the values obtained in this experiment. The Lys:CP ratio was 4.05 and 3.7 for wheat middlings and red dog, respectively, and the value for wheat middlings is closer to the value of 4.5% reported by NRC (2012). The relatively high concentrations of Arg, Asp, and Glu in wheat middlings and red dog have 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

Table 5. Apparent ileal digestibility (%) of crude protein and amino acids in wheat middlings and red dog[1]

	Wheat middlings source												Red	Wheat middlings^2			Wheat middlings vs. red dog^3	
Item	1	2	3	4	5	6	7	8	9	10	Mean	SD	dog	SEM	*P*-value	LSD	SEM	*P*-value
CP	35.0	42.4	25.7	31.6	35.4	27.6	36.5	32.6	26.1	18.1	31.1	6.9	47.0	4.72	0.027	12.56	4.30	0.001
Indispensable, AA																		
Arg	59.1	63.5	60.0	60.3	65.1	57.3	60.9	59.0	63.4	56.9	60.5	2.7	60.8	3.64	0.848	9.98	3.80	0.959
His	71.8	67.4	67.6	67.7	68.2	65.5	67.1	70.6	65.2	65.5	67.7	2.2	63.6	1.64	0.112	4.52	1.57	0.017
Ile	60.8	59.8	57.9	62.5	60.2	51.6	53.3	59.6	55.0	51.8	57.3	4.0	72.5	2.05	0.001	5.65	2.03	< 0.001
Leu	65.2	62.9	60.9	64.9	63.5	58.5	60.4	63.7	59.8	56.6	61.6	2.8	73.6	1.90	0.028	5.23	1.84	< 0.001
Lys	21.4	37.7	27.1	36.4	31.4	30.9	30.2	33.0	31.3	22.0	30.1	5.4	54.2	3.53	0.022	9.50	3.10	< 0.001
Met	68.6	66.4	67.1	66.5	70.7	64.2	68.0	67.1	65.2	64.2	66.8	2.0	86.2	1.28	0.035	3.53	1.24	< 0.001
Phe	66.7	63.3	62.1	65.2	64.5	58.5	61.0	65.0	60.7	56.6	62.4	3.2	75.5	1.84	0.005	5.06	1.79	< 0.001
Thr	43.6	42.3	39.5	43.8	42.4	31.0	35.9	39.4	37.4	33.9	38.9	4.3	76.1	2.57	0.006	7.02	2.45	< 0.001
Trp	70.0	59.4	61.4	61.6	61.5	58.2	52.5	59.8	62.7	53.2	60.0	4.9	78.2	2.03	< .0001	5.58	1.94	< 0.001
Val	51.7	50.6	46.2	50.6	49.9	42.2	44.8	48.0	47.0	38.9	47.0	4.1	53.7	2.42	0.006	6.65	2.41	0.010
Dispensable, AA																		
Ala	35.3	41.5	33.4	41.6	40.3	32.5	35.9	34.1	35.8	26.5	35.7	4.6	53.2	3.46	0.058	9.37	3.35	< 0.001
Asp	53.1	54.6	50.2	53.8	54.7	47.6	49.2	52.9	51.5	47.3	51.5	2.8	59.8	2.12	0.087	5.83	2.06	0.001
Cys	62.2	59.8	64.0	60.5	57.6	54.3	55.7	62.2	60.1	56.0	59.3	3.2	39.8	1.74	0.002	4.78	1.90	< 0.001
Glu	77.4	75.4	75.8	77.1	75.7	72.2	72.8	77.6	74.6	70.0	74.9	2.5	85.9	1.24	0.001	3.42	1.18	< 0.001
Ser	57.8	54.2	53.7	55.4	54.2	46.8	51.4	54.9	52.9	43.1	52.5	4.4	54.9	2.41	0.003	6.63	2.48	0.290
Tyr	58.7	57.9	53.5	60.2	57.9	45.6	50.0	57.1	51.6	48.0	54.0	5.0	72.4	2.45	0.000	6.73	2.40	< 0.001
Total AA	60.1	59.8	58.0	61.1	61.5	53.0	55.8	59.6	56.6	51.7	57.7	3.4	71.8	1.90	0.004	5.23	1.88	< 0.001

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

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

[3] Comparison of wheat middlings and red dog.

the main proteins in both rice bran 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 ADF was 10.81% on average. These values are within the range of values reported by Cromwell et al. (2000), Rostagno et al. (2011), and NRC (2012), but greater than reported by Shi and Noblet (1993) and Sauvant et al. (2004).

The concentrations of NDF and ADF in red dog were 11.81% and 3.37%, respectively, and these values agree with reported values (Huang et al., 2012). Lower concentrations of NDF, ADF, and lignin in red dog compared with other wheat coproducts such as wheat shorts or wheat middlings have been reported (Huang et al., 1999; Huang et al., 2012; NRC, 2012) and are 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 were used as well as growing conditions of wheat (Erickson et al., 1985).

Digestibility of Crude Protein and Amino Acids

The AID of CP in wheat middlings was on average 31.1%, but the SD was 6.9 (Table 5). 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 from 30.1% for Lys to 67.7% for His, and the AID of indispensable AA in red dog ranged from 53.7% for Val to 86.2% for Met. The AID of Arg and His in wheat middlings was 60.5% and 67.7%, respectively, and no differences were observed among sources. There was a tendency ($P = 0.058$ and 0.087, respectively) for differences among sources of wheat middlings for the AID of Ala and Asp, and for all other dispensable 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, the AID of all other AA in red dog was greater ($P < 0.05$) than in wheat middlings.

The average SID of CP in wheat middlings was 61.5 ± 5.1%, and there were no differences among the

Table 6. Standardized ileal digestibility (%) of crude protein and amino acids in wheat middlings and red dog[1,2]

	Wheat middlings source												Red dog	Wheat middlings[3]			Wheat middlings vs. red dog[4]	
Item	1	2	3	4	5	6	7	8	9	10	Mean	SD		SEM	*P*-value	LSD	SEM	*P*-value
CP	65.2	67.1	61.1	57.0	64.6	58.7	67.2	64.2	58.1	51.5	61.5	5.1	78.5	4.52	0.258	12.37	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	3.92	0.124
His	81.7	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	0.144	4.52	1.58	0.126
Ile	72.4	71.4	70.0	73.9	72.4	64.8	65.9	71.3	67.7	63.9	69.4	3.5	84.2	2.05	0.005	5.65	2.03	< 0.001
Leu	75.8	73.5	72.3	75.3	74.3	69.4	71.1	74.5	71.0	67.7	72.5	2.7	84.4	1.90	0.053	5.23	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	0.041	9.68	3.19	<0.0001
Met	75.4	73.2	74.0	73.5	77.0	71.1	74.3	73.9	72.2	71.0	73.6	1.8	90.6	1.28	0.071	3.53	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	1.84	0.016	5.06	1.79	< 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	4.0	87.3	2.65	0.022	7.25	2.57	< 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	88.6	2.03	0.000	5.58	1.94	< 0.001
Val	68.4	66.9	64.0	66.7	66.7	59.5	61.6	65.2	64.4	56.2	64.0	3.8	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	77.5	3.70	0.095	10.15	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	0.218	6.45	2.28	< 0.001
Cys	76.2	73.9	78.1	74.8	72.7	69.4	70.8	76.3	74.3	70.1	73.6	2.9	57.4	1.74	0.009	4.78	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	74.0	67.0	71.4	74.1	72.2	66.7	72.5	3.3	74.9	2.19	0.033	6.01	2.03	0.264
Tyr	72.5	71.0	68.3	73.5	71.8	62.3	64.8	70.9	66.4	62.7	68.4	4.1	85.5	2.45	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	70.9	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 pigs fed the 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, 0.64; Trp, 0.09; Val 0.67; Ala, 0.79; Asp, 0.89; Cys, 0.23; Glu, 1.09; Ser, 0.61; and Tyr, 0.27.

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

[4] Comparison of wheat middlings and red dog.

10 sources of wheat middlings (Table 6). 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 ± 1.8%) and the SID of Ala (54.8 ± 4.9%) tended ($P = 0.071$ and $P = 0.095$, 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 coproducts 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 1 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 coproducts such as solubility, viscosity, and water-holding capacity may influence the digestibility of AA (Souffrant, 2001). 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), further indicating the negative effects of wheat fiber on SID of AA.

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 SID of Lys that was observed for wheat middlings in this experiment is, therefore, most likely a result of heat damage during processing of the grain because heat damage will reduce the digestibility of Lys more than that of other AA (Fontaine et al., 2007; González-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 the SID of Lys in a feed ingredient is less than the SID 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 was determined in this experiment was less than the SID of Thr, further indicates that the sources of wheat middlings used in this experiment were 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 the manufacturing procedures generally used in the processing of wheat 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.

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