Published August 1, 2016

Wheat bran reduces concentrations of digestible, metabolizable, and net energy in diets fed to pigs, but energy values in wheat bran determined by the difference procedure are not different from values estimated from a linear regression procedure

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ABSTRACT: An experiment was conducted to determine effects on DE, ME, and NE for growing pigs of adding 15 or 30% wheat bran to a corn–soybean meal diet and to compare values for DE, ME, and NE calculated using the difference procedure with values obtained using linear regression. Eighteen barrows (54.4 ± 4.3 kg initial BW) were individually housed in metabolism crates. The experiment had 3 diets and 6 replicate pigs per diet. The control diet contained corn, soybean meal, and no wheat bran. Two additional diets were formulated by mixing 15 or 30% wheat bran with 85 or 70% of the control diet, respectively. The experimental period lasted 15 d. During the initial 7 d, pigs were adapted to their experimental diets and housed in metabolism crates and fed 573 kcal ME/kg $BW^{0.6}$ per day. On d 8, metabolism crates with the pigs were moved into open-circuit respiration chambers for measurement of O_2 consumption and CO_2 and CH_4 production. The feeding level was the same as in the adaptation period, and feces and urine were collected during this period. On d 13 and 14, pigs were fed 225 kcal ME/kg $BW^{0.6}$ per day, and pigs were then fasted for 24 h to obtain fasting heat production. Results of the experiment indicated that the apparent total tract digestibility of DM, GE, crude fiber, ADF, and NDF linearly decreased ($P \leq 0.05$) as wheat bran inclusion increased in the diets. The daily O_2 consumption and CO_2 and CH_4 production by pigs fed increasing concentrations of wheat bran linearly decreased ($P \leq 0.05$), resulting in a linear decrease ($P \leq 0.05$) in heat production. The DE (3,454, 3,257, and 3,161 kcal/kg for diets containing 0, 15, and 30% wheat bran, respectively for diets containing 0, 15, and 30% wheat bran, respectively), ME (3,400, 3,209, and 3,091 kcal/kg for diets containing 0, 15, and 30% wheat bran, respectively), and NE (1,808, 1,575, and 1,458 kcal/kg for diets containing 0, 15, and 30% wheat bran, respectively) of diets decreased (linear, $P \leq 0.05$) as wheat bran inclusion increased. The DE, ME, and NE of wheat bran determined using the difference procedure were 2,168, 2,117, and 896 kcal/kg, respectively, and these values were within the 95% confidence interval of the DE (2,285 kcal/kg), ME (2,217 kcal/kg), and NE (961 kcal/kg) estimated by linear regression. In conclusion, increasing the inclusion of wheat bran in a corn–soybean meal based diet reduced energy and nutrient digestibility and heat production as well as DE, ME, and NE of diets, but values for DE, ME, and NE for wheat bran determined using the difference procedure were not different from values determined using linear regression.

Key words: dietary fiber, difference procedure, energy concentration, heat production, pig, wheat bran

J. Anim. Sci. 2016.94:3012–3021
doi:10.2527/jas2016-0352

INTRODUCTION

In the United States, the energy concentration of diets fed to pigs is most often evaluated using DE or ME systems (Whitney, 2005), but it is possible that a more accurate estimate of the utilizable energy of pig diets may be obtained using a NE system because the energy value of fiber may be more accurately assessed in the NE system (Noblet and Van Milgen, 2013). An increased use of dietary fiber in pig diets has been observed over the last decade because of increased inclusion of coproducts in the diets, and this

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Received January 31, 2016.
Accepted April 22, 2016.

is expected to continue in the future (Woyengo et al., 2014). Therefore, there is a need to determine the energy contribution from fiber-rich coproducts, but the effect of dietary fiber on heat production (**HP**) and NE of diets remains unclear (Noblet and Van Milgen, 2004). Increased fiber in diets may increase HP because of increased feed intake and increased hindgut fermentation (Jørgensen et al., 1996), whereas physical activity may be reduced if fiber in the diet is increased, which may cause a decrease in HP (Schrama et al., 1998).

Values for DE and ME in feed ingredients are most often determined using the difference procedure, whereas values for NE most often are determined using prediction equations or a regression procedure (Noblet et al., 1994; NRC, 2012). Values for NE have also been determined using the difference procedure (Kil et al., 2011; Stewart et al., 2013; Liu et al., 2014), but to our knowledge, values determined using the difference procedure and the regression procedure have not been compared. Therefore, the first objective of this experiment was to test the hypothesis that increased dietary fiber in the form of wheat bran added to a corn–soybean meal diet will increase HP and reduce calculated values for DE, ME, and NE when fed to growing pigs. The second objective was to test the hypothesis that the DE, ME, and NE of wheat bran can be determined using the difference procedure with the same efficacy as using linear regression.

MATERIALS AND METHODS

The protocol for this experiment was approved by the Institutional Animal Care and Use Committee at China Agricultural University and the experiment was conducted in the Open-Circuit Respiration Laboratory at the Swine Nutrition Research Centre of the National Feed Engineering Technology Research Center (Chengde, Hebei Province, China).

Indirect Calorimetry Equipment

Six open-circuit respiration chambers with a volume of approximately 7.8 m^3 were used based on a design similar to that described by Van Milgen et al. (1997). Gas was continuously extracted from the respiration chamber by a vacuum pump. The respiration chamber was maintained at a constant temperature and humidity using an air conditioner and a heater. Temperature and atmospheric pressure in the chamber were measured and used to calculate the standard temperature and pressure (0°C and 101 kPa) extraction rate. Oxygen inside and outside the chamber was measured with a paramagnetic differential analyzer (Oxymat 6E; Siemens AG, Munich, Germany), whereas CO_2, CH_4, and NH_3 were measured with infrared analyzers (Ultramat 6E; Siemens AG). The analyzers had a range of measurement of 19.5 to 21.0% for O_2, 0 to 1% for CO_2, 0 to 0.1% for CH_4, and 0 to 0.1% for NH_3 with a sensitivity of 0.2% within the measurement range. The gas extraction rate was measured by a mass flow meter (Alicat Scientific, Inc., Tucson, AZ). Two respiration chambers shared 1 gas analyzer. Gas concentrations in each chamber were measured at 5-min intervals throughout the entire experiment.

Animals, Housing, Experimental Design, and Diets

Eighteen Duroc × (Landrace × Large White) barrows with an initial BW of 54.4 ± 4.3 kg were used in a randomized complete block design with block being the period. Six open-circuit respiration chambers were available and, therefore, the 18 pigs were divided into 3 periods and used in groups of 6. There were 3 experimental diets allowing for 2 replicates per period and 6 replicates per diet for the overall experiment. All pigs were housed in metabolism crates throughout the experiment. The metabolism crates were equipped with a feeder and a water trough that prevented contamination of feces and urine with feed and water. Crates had fully slatted floors with a screen underneath for fecal collection and a urine tray underneath the fecal screen, which allowed for the total, but separate, collection of urine and feces from each pig. Each experimental period lasted 15 d with the initial 7 d being the adaptation period to the crates and experimental diets. On d 8, crates were rolled into the respiration chambers, and feces and urine were collected during the following 5 d. This period was followed by a 2-d prefasting period and a 24-h fast. Individual pig weights were recorded at the beginning of the experiment, at the beginning of the collection period, and at the beginning and conclusion of the fasting period. Gas measurements commenced at 0700 h on d 8 of each period when pigs entered the respiration chambers and stopped at 0700 h on d 15 of each period. Before and after the experiment, respiration chambers were checked for accuracy by using an alcohol check test (Benedict and Tompkins, 1916). The temperature in the respiration chambers was maintained at 22°C during the 5-d energy balance, 23°C during the 2-d prefasting period, and 24°C during the 24-h fast. The relative humidity in the chambers was maintained at 70% and the air velocity was 0.1 m/s.

Corn, soybean meal, and wheat bran were procured from local commercial Chinese feed mills (Table 1). Three experimental diets were formulated (Table 2). The basal diet contained corn and soybean meal and no wheat bran. Two additional diets were formulated by mixing 15 or 30% wheat bran with 85 or 70% of the basal diet, respectively. The basal diet was overformulated compared with expected nutrient requirements to ensure that all diets met current requirement estimates

for standardized ileal digestible indispensable AA, standardized total tract digestible P, vitamins, and minerals (NRC, 2012). The quantity of feed provided per pig daily during the adaptation period was calculated as 573 kcal ME/kg $BW^{0.6}$ because results of previous research in this facility had indicated that this amount of feed is close to the voluntary feed intake of growing pigs (Zhang et al., 2014). The same amount of feed was also provided during the energy balance period and provided at 0700 and 1600 h, at which times respiration chamber doors were opened for approximately 1 h and gas measurements during these time periods were disregarded from the final calculations. The quantity of feed provided per pig daily during the 2-d prefasting period was calculated as 225 kcal ME/kg $BW^{0.6}$ and urine was collected during this time. Pigs were fasted for the final 24 h in the respiration chambers and urine was collected during this time. Feces were not collected during the prefasting and the fasting period because only the quantity of urine excreted is necessary for the calculation of fasting HP (**FHP**). The prefasting period was used to adapt pigs to the fasting period because results of previous research from the same facility indicated that the variability in gas measurements during the 24-h fast was much less if the fasting period is preceded by a prefasting period, resulting in a better estimate of FHP (unpublished data, Liu et al., 2014). Water was available on an ad libitum basis throughout the experiment.

During the 5-d energy balance, total, but separate, collection of feces and urine was conducted. Feces were collected each day when the chamber doors were opened for feeding and immediately stored at −20°C. Urine was collected each morning at 0700 h over a preservative of 50 mL of 6 *N* HCl. Each day, the total urine volume produced by each pig was measured and a 5% aliquot was filtered through cheesecloth, transferred into a plastic bottle, and stored at −20°C. At the conclusion of the collection period, urine samples were thawed and thoroughly mixed and 50 mL of urine from each pig was collected into screw-cap tubes and this sample was used for analysis. At the conclusion of the 5-d energy balance period, feces were thawed, mixed, and weighed and duplicate subsamples of approximately 350 g were dried for 72 h in a 65°C drying oven. Subsamples were weighed again after drying, ground through a 1-mm screen, and used for analysis.

Table 1. Analyzed nutrient composition of ingredients (as-fed basis)

	Ingredient		
Item	Corn	Soybean meal	Wheat bran
GE, kcal/kg	3,867	4,192	3,969
DM, %	86.87	86.37	87.50
Ash, %	1.21	6.63	5.15
AEE,[1] %	3.78	1.76	4.09
CP (N × 6.25), %	8.05	46.89	17.28
Crude fiber, %	2.15	4.97	11.84
ADF, %	3.76	8.86	13.77
NDF, %	8.41	10.31	44.76
Insoluble dietary fiber, %	10.78	17.67	48.00
Soluble dietary fiber, %	1.71	0.91	2.90
Total dietary fiber, %	12.49	18.58	50.90
Starch, %	67.28	2.31	11.26
Fructose, %	0.22	1.12	0.75
Glucose, %	1.13	3.55	1.61
Sucrose, %	0.63	5.92	0.65
Maltose, %	0.16	0.11	0.10
Raffinose, %	0.13	1.52	1.12
Stachyose, %	ND[2]	4.16	0.09
Verbascose, %	ND	0.37	ND
Indispensable AA, %			
Arg	0.35	3.46	1.16
His	0.23	1.22	0.46
Ile	0.28	2.21	0.52
Leu	0.98	3.73	1.01
Lys	0.25	2.97	0.68
Met	0.18	0.64	0.23
Phe	0.38	2.45	0.63
Thr	0.29	1.86	0.53
Trp	0.06	0.73	0.19
Val	0.38	2.28	0.78
Dispensable AA, %			
Ala	0.59	2.09	0.80
Asp	0.54	5.48	1.20
Cys	0.18	0.64	0.33
Glu	1.45	8.42	2.84
Gly	0.30	2.03	0.90
Pro	0.69	2.34	0.95
Ser	0.38	2.28	0.65
Tyr	0.25	1.77	0.40
Total AA, %	7.94	46.94	14.45

[1]AEE = acid hydrolyzed ether extract.

[2]ND = not detectable.

Sample Analysis and Calculations

Diet, ingredient, and fecal samples were analyzed for DM (method 930.15; AOAC, 2007), ash (method 942.05; AOAC, 2007), crude fiber (method 978.10; AOAC, 2007), ADF (method 973.18; AOAC, 2007), and NDF (Holst, 1973). All diets, ingredients, and fecal samples were analyzed for CP using the combustion procedure (method 990.03; AOAC, 2007) on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ). Aspartic acid was used as a calibration standard and CP was calculated as N × 6.25. Diets and ingredients were analyzed for AA on a Hitachi AA Analyzer (model L8800; Hitachi High Technologies America, Inc., Pleasanton, CA) using ninhydrin for postcolumn derivatization and norleucine as

Table 2. Ingredient composition and calculated and analyzed composition of experimental diets (as-fed basis)

	Diet		
Item	Basal	15% Wheat bran	30% Wheat bran
Ingredients, %			
Corn	79.47	67.55	55.63
Soybean meal (47% CP)	16.00	13.60	11.20
Wheat bran	0.00	15.00	30.00
Limestone	1.40	1.19	0.98
Dicalcium phosphate	1.00	0.85	0.70
L-Lys HCl	0.62	0.53	0.43
DL-Met	0.06	0.05	0.04
L-Thr	0.15	0.13	0.11
L-Trp	0.03	0.03	0.02
Salt	0.57	0.48	0.40
Vitamin–mineral premix[1]	0.70	0.60	0.50
Total	100.00	100.00	100.00
Calculated composition[2]			
ME, kcal/kg	3,225	3,089	2,953
CP, %	13.68	13.89	14.10
SID[3] Lys, %	1.05	0.95	0.85
STTD[4] P, %	0.28	0.32	0.36
Analyzed composition			
GE, kcal/kg	3,775	3,797	3,846
DM, %	87.10	86.95	86.87
CP (N × 6.25), %	15.05	15.30	15.43
AEE,[5] %	2.59	2.85	2.95
Ash, %	5.10	4.72	4.87
Crude fiber, %	3.12	4.17	5.17
ADF, %	5.07	5.83	6.96
NDF, %	9.24	14.96	20.55
Insoluble dietary fiber, %	15.02	20.45	25.51
Soluble dietary fiber, %	3.95	3.61	2.11
Total dietary fiber, %	18.97	24.06	27.62
Starch, %	56.42	53.23	50.11
Indispensable AA, %			
Arg	0.88	0.92	0.94
His	0.39	0.40	0.40
Ile	0.60	0.58	0.55
Leu	1.40	1.34	1.25
Lys	1.03	1.02	0.97
Met	0.27	0.29	0.27
Phe	0.72	0.70	0.67
Thr	0.71	0.62	0.61
Trp	0.18	0.20	0.20
Val	0.69	0.71	0.71
Dispensable AA, %			
Ala	0.83	0.82	0.80
Asp	1.38	1.31	1.26
Cys	0.25	0.25	0.27
Glu	2.60	2.63	2.61
Gly	0.60	0.64	0.67
Pro	0.94	0.95	0.92
Ser	0.68	0.66	0.64
Tyr	0.52	0.49	0.47
Total AA, %	14.94	14.79	14.46

[1]The vitamin–micromineral premix provided the following quantities of vitamins and microminerals per kilogram of complete diet: 5,512 IU vitamin A, 2,200 IU vitamin D_3, 30 IU vitamin E, 2.2 mg vitamin K_3, 27.6 μg vitamin B_{12}, 1.5 mg thiamine, 4.0 mg riboflavin, 14 mg pantothenic acid, 30 mg niacin, 400 mg choline chloride, 0.7 mg folacin, 3 mg pyridoxine, 44 μg biotin, 120 mg Fe, 100 mg Cu, 75 mg Zn, 40 mg Mn, 0.3 mg I, and 0.3 mg Se.

[2]Calculated from NRC (2012) values.

[3]SID = standardized ileal digestible.

[4]STTD = standardized total tract digestible.

[5]AEE = acid hydrolyzed ether extract.

the internal standard (method 982.30 E(a, b c); AOAC, 2007). Urinary N was determined as Kjeldahl N (Thiex et al., 2002). Acid hydrolyzed ether extract was determined in all diet and ingredient samples by acid hydrolysis using 3 *N HCl (*Sanderson, 1986) followed by crude fat extraction using petroleum ether (method 2003.06; AOAC, 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). Diets and ingredients also were analyzed for total dietary fiber, insoluble dietary fiber, and soluble dietary fiber according to Prosky et al. (1992). Monosaccharides and oligosaccharides in the ingredients were analyzed as described by Cervantes-Pahm and Stein (2010). Total starch was analyzed in all diets and ingredients by the glucoamylase procedure (method 979.10; AOAC, 2007). Diet, ingredient, fecal, and urine samples were analyzed in duplicate for GE using bomb calorimetry (model 6300; Parr Instruments, Moline, IL), and the apparent total tract digestibility (**ATTD**) of GE in each diet was calculated (Adeola, 2001).

The energy lost in the feces and in the urine was calculated, and the quantities of DE and ME in each of the 3 diets were calculated (Adeola, 2001). Although CH_4 production by pigs was measured, it was not included in the calculation of ME because most ME values disregard energy losses of CH_4, even though energy losses of CH_4 can range from 0.1 to 3.0% of DE (Shi and Noblet, 1993). The DE and ME in the basal diet then were multiplied by 85 or 70% to calculate the contribution from the basal diet to the DE and ME in diets containing 15 or 30% wheat bran, respectively. The DE and ME in wheat bran then were calculated by difference (Stewart et al., 2013).

Concentrations of O_2, CO_2, and CH_4 that were measured during the period pigs were in the respiration chambers were used to calculate O_2 consumption and CO_2 and CH_4 production during each 5 min interval, and these values were then summed over a 24-h period. Heat production was calculated from gas exchanges and urinary losses of N according to Brouwer (1965) using Eq. [1]:

$$HP = 3.866 \times O_2 + 1.200 \times CO_2 - 0.518 \times CH_4 - 1.431 \times \text{urinary N}, \quad [1]$$

in which HP is expressed in kilocalories; O_2, CO_2, and CH_4 are expressed in liters; and urinary N is expressed in grams.

Fasting HP was calculated using the same equation but using gas exchanges and urinary losses of N during the 24-h fasting period.

Retention of dietary energy (**RE**) was calculated according to Ayoade et al. (2012) using Eq. [2]:

$$RE = \text{ME intake} - HP, \quad [2]$$

in which RE, ME, and HP are expressed in kilocalories.

Retention of energy as protein ($\mathbf{RE_P}$) was calculated according to Ewan (2001) as N retention (g) × 6.25 × 5.68 (kcal/g). Retention of energy as lipid ($\mathbf{RE_L}$) was calculated as the difference between RE and RE_P (Labussière et al., 2009).

Net energy of each diet was calculated according to Noblet et al. (1994) using Eq. [3]:

$$NE = (RE + FHP)/DMI, \quad [3]$$

in which NE is expressed in kilocalories per kilogram DM, RE and FHP are expressed in kilocalories, and DMI is expressed in kilograms.

After the NE of each diet was calculated, the NE in wheat bran also was calculated by difference as described previously for the calculation of DE and ME in wheat bran (Stewart et al., 2013). The respiration quotient (**RQ**) was calculated as the ratio between CO_2 production and O_2 consumption (Noblet et al., 2001).

Statistical Analysis

Homogeneity of variances was confirmed using the UNIVARIATE procedure (SAS Inst. Inc., Cary, NC). Outliers were determined as any value that deviated from the treatment mean by ± 2 SD. A pig fed the 30% wheat bran diet died during the experiment and was not included in the calculations. Data were analyzed using the MIXED procedure. The model included diet as the fixed effect and pig and period as random effects. Least squares means were calculated for each independent variable. Orthogonal polynomials were used to determine linear and quadratic effects of diet. Regression equations to estimate the DE, ME, and NE of wheat bran were developed using the REG procedure in SAS following methods of Young et al. (1977) and Noblet et al. (1993). The DE, ME, and NE of wheat bran then was estimated by solving the prediction equations when wheat bran inclusion was equal to 100%. The CLB statement in SAS was used to determine the 95% confidence levels for the regression coefficients used for estimating the DE, ME, and NE of wheat bran. The DE, ME, and NE of wheat bran obtained using the difference procedure was considered not different from the DE, ME, and NE of wheat bran estimated using linear regression if the values were within the 95% confidence interval for the DE, ME, and NE of wheat bran estimated using linear regression. The pig was the experimental unit and a probability of $P \leq 0.05$ was considered significant and $0.05 < P \leq 0.10$ was considered a trend.

RESULTS AND DISCUSSION

The wheat bran fed in this experiment contained 11.84, 13.77, and 44.76% crude fiber, ADF, and NDF, respectively, compared with average values of 7.77, 11.00, and 32.28%, respectively (NRC, 2012). The concentrations of soluble, insoluble, and total dietary fiber in the wheat bran used in this experiment were 2.9, 48.0, and 50.9%, respectively, whereas Jaworski et al. (2015) reported the concentration of soluble, insoluble, and total dietary fiber in wheat bran to be 3.5, 34.9, and 38.4%, respectively. The concentration of starch in the wheat bran fed in the current experiment was 11.26% whereas the NRC (2012) and Jaworski et al. (2015) reported the starch concentration in wheat bran to be 22.56 and 15.67%, respectively. These differences indicate that the source of wheat bran fed in this experiment was produced from a flour mill that was more efficient in extracting the starch from the wheat compared with those used to produce the wheat bran referred to by the NRC (2012) and Jaworski et al. (2015). The soybean meal fed in this experiment contained 4.97% crude fiber, 8.86% ADF, 10.31% NDF, 5.92% sucrose, 1.52% raffinose, and 4.16% stachyose, which is within the range of values previously reported (Baker and Stein, 2009; Cervantes-Pahm and Stein, 2010; NRC, 2012). The concentrations of CP and AA in the soybean meal were also comparable with concentrations published by the NRC (2012). The nutrient composition of the corn fed in this experiment also was in agreement with previous values (NRC, 2012; Rojas et al., 2013). The analyzed nutrient and energy concentrations in experimental diets were not different from calculated values. The concentration of GE and insoluble dietary fiber increased and the concentration of starch and soluble dietary fiber decreased as wheat bran inclusion increased in the diets.

Final BW of pigs linearly decreased ($P \leq 0.05$) as the concentration of wheat bran increased in the diet (Table 3). These results are in agreement with data for growing pigs fed diets containing 30% soybean hulls or wheat middlings compared with pigs fed a corn–soybean meal–based diet (Stewart et al., 2013). The ATTD of DM, GE, CP, crude fiber, ADF, and NDF linearly

Table 3. Energy balance and daily gas consumption and gas production by growing pigs fed experimental diets

Item[1]	Diet			Pooled SEM	*P*-value	
	Basal	15% Wheat bran	30% Wheat bran		Linear	Quadratic
Initial BW, kg	54.37	54.33	54.53	2.63	0.77	0.81
Final BW, kg	59.07	58.57	57.87	2.66	0.02	0.82
Daily feed intake, kg	1.89	1.84	1.78	0.05	0.07	0.87
Total feed intake, kg	9.43	9.19	8.90	0.28	0.20	0.93
GE intake, kcal	35,578	34,898	32,974	1,539	0.25	0.75
N intake, g	226.91	224.90	227.19	8.09	0.97	0.75
Dry feces output, kg	0.76	1.19	1.56	0.05	<0.01	0.58
GE in feces, kcal/kg	3,999	4,183	4,225	28.41	<0.01	0.06
Fecal GE output, kcal	3,035	4,957	6,599	163.12	<0.01	0.43
N in feces, %	2.78	2.32	2.32	0.07	<0.01	0.01
Fecal N output, g	20.92	27.55	36.17	1.20	<0.01	0.47
DE in diet, kcal/kg	3,454	3,257	3,161	33.10	<0.01	0.18
DE in diet, kcal/kg DM	3,966	3,746	3,639	38.10	<0.01	0.20
DE in diet, kcal/kg $BW^{0.6}$	306.20	290.96	282.32	8.33	<0.01	0.53
Urine output, kg	16.63	13.22	11.53	2.23	0.05	0.66
Daily urine output, kg	3.13	2.45	2.04	0.29	<0.01	0.42
GE in urine, kcal/kg	43.80	50.93	61.67	11.59	0.16	0.86
Urinary GE output, kcal/d	128.83	116.65	135.35	22.62	0.51	0.08
ME in diet, kcal/kg	3,400	3,209	3,091	31.63	<0.01	0.34
ME in diet, kcal/kg DM	3,904	3,690	3,558	36.40	<0.01	0.36
ME in diet, kcal/kg $BW^{0.6}$	302.22	285.18	276.10	8.59	<0.01	0.52

Continued

decreased ($P \leq 0.05$) as wheat bran inclusion increased in the diets (Table 4). There also was a tendency for a quadratic decrease ($P \leq 0.10$) in the ATTD of ADF by pigs as wheat bran inclusion increased in the diets. Although the GE in diets increased from 3,775 to 3,797 and 3,846 kcal/kg as 15 or 30% wheat bran was included, the DE in the diets linearly decreased ($P \leq 0.05$) from 3,454 to 3,257 and 3,161 kcal/kg as wheat bran inclusion increased in the diets. The ME of diets linearly decreased ($P \leq 0.05$) from 3,400 to 3,209 and 3,091 kcal/kg as wheat bran inclusion increased. Total HP and daily HP by pigs decreased (linear, $P \leq 0.05$) as wheat bran inclusion increased in diets, and this observation contradicted our hypothesis. Previous data indicated that there is no difference in HP between 50-kg pigs fed a high-starch diet and pigs fed a high-fiber diet (Schrama et al., 1996). Inclusion of 0, 5, 10, or 15% sugar beet pulp silage in diets fed to group-housed growing pigs also did not affect HP (Schrama et al., 1998), and group-housed growing pigs fed a corn-based diet did not have a different HP compared with pigs fed a diet containing corn plus 15% wheat straw (Schrama and Bakker, 1999). Likewise, inclusion of 0, 15, or 30% wheat–corn distillers' dried grains with solubles in diets for pigs weighing 18.5 kg did not affect HP (Ayoade et al., 2012). Therefore, it appears that in most experiments, HP either does not change or is reduced as the concentration of fiber in the diets increases. It is possible that as dietary fiber concentration increases, the HP related to physical activity decreases, resulting in no change or potentially a decrease in HP (Schrama and Bakker, 1999). However, physical activity was not measured in the current experiment and we are, therefore, not able to verify that the reason a reduction in HP was observed is due to a reduction in physical activity.

The concentration of N in the urine linearly decreased ($P \leq 0.05$) by pigs fed diets containing increasing concentrations of wheat bran, but urinary N output was not different among treatments. There was a linear decrease ($P \leq 0.05$) in O_2 consumption from 663.71 to 659.82 and 636.38 L/d as wheat bran inclusion in diets increased. Carbon dioxide and CH_4 production by pigs also linearly decreased ($P \leq 0.05$) from 700.42 to 678.27 and 656.19 L/d and from 4.83 to 3.21 and 1.51 L/d, respectively, as wheat bran inclusion increased in the diets. The CH_4 excretion values for growing pigs in the current experiment are in agreement with values previously reported for CH_4 excretion in growing pigs (Christensen and Thorbek, 1987). The RQ of pigs fed experimental diets decreased (linear, $P \leq 0.05$) from 1.06 to 1.03 and 1.03 as wheat bran inclusion in the diets increased, which may be indicative of the diets becoming limited in energy supply.

Chinese Latang gilts fed a corn–soybean meal based diet with 21% wheat bran produced 3.9 L of CH_4 per day (Cao et al., 2013). In the current study, pigs fed 15% wheat bran produced 3.21 L of CH_4 per day. Diets containing greater quantities of insoluble dietary fiber promote gut

Table 3. (cont.)

Item[1]	Diet			Pooled SEM	*P*-value	
	Basal	15% Wheat bran	30% Wheat bran		Linear	Quadratic
Efficiency of ME						
ME:DE ratio	0.98	0.98	0.98	<0.01	0.30	0.54
5-d total HP, kcal	16,997	16,832	15,085	614.43	0.04	0.31
5-d total HP, kcal/kg $BW^{0.6}$	1,509	1,457	1,349	54.67	0.03	0.64
Daily HP, kcal	3,391	3,347	3,229	111.45	0.02	0.50
Daily HP, kcal/kg $BW^{0.6}$	300.79	297.11	287.54	5.93	0.02	0.55
HP, kcal/kg FI	1,797	1,826	1,756	40.89	0.32	0.16
Urinary N, %	0.42	0.50	0.64	0.06	<0.01	0.56
Urinary N output, g/d	13.08	12.10	11.82	1.56	0.21	0.68
O_2 consumption, L/d	663.75	659.83	634.31	24.49	0.02	0.32
CO_2 production, L/d	700.27	678.05	653.70	19.25	<0.01	0.92
CH_4 production, L/d	4.83	3.21	1.48	0.42	<0.01	0.85
RQ	1.06	1.03	1.03	0.01	0.01	0.22
FHP, kcal	2,065	1,972	2,194	142.01	0.33	0.18
FHP, kcal/kg $BW^{0.6}$	192.75	177.40	198.08	13.22	0.74	0.22
Fasting RQ	0.74	0.74	0.73	0.02	0.90	0.66
5-d total ME intake, kcal	32,041	29,380	27,238	912.03	<0.01	0.82
ME intake, kcal/d	6,408	5,876	5,645	178.64	<0.01	0.04
5-d total RE, kcal	15,044	12,548	12,153	761.19	0.01	0.24
Daily RE, kcal	3,010	2,617	2,400	103.57	<0.01	0.24
Daily RE, kcal/kg $BW^{0.6}$	266.87	223.85	216.28	12.34	0.01	0.26
5-d total RE, kcal/kg	1,595	1,363	1,360	60.05	0.01	0.14
Daily RE, kcal/kg	1,611	1,372	1,293	42.71	<0.01	0.02
Retained protein, g/d	179.24	166.56	164.43	10.12	0.20	0.59
RE_P, kcal/d	1,018	946.05	933.95	57.47	0.20	0.59
RE_P, kcal per d/kg $BW^{0.6}$	90.33	83.89	83.46	4.09	0.22	0.53
Retained lipid, g/d	221.19	173.73	166.29	16.68	0.03	0.30
RE_L, kcal/d	1,991	1,564	1,497	150.15	0.03	0.30
RE_L, kcal per d/kg $BW^{0.6}$	176.54	139.96	132.83	12.98	0.03	0.36
NE, kcal/kg	1,808	1,575	1,462	236.89	<0.01	0.17
NE, kcal/kg DM	2,076	1,812	1,683	272.4	<0.01	0.17
NE, kcal/kg $BW^{0.6}$	160.97	140.46	129.86	21.35	<0.01	0.21
Efficiencies of NE						
NE:DE ratio	0.53	0.49	0.49	0.02	0.24	0.34
NE:ME ratio	0.54	0.49	0.51	0.02	0.23	0.25

[1]FHP = fasting heat production; FI = feed intake; HP = heat production; RE = retention of dietary energy; RE_L = retention of energy as lipid; RE_P = retention of energy as protein; RQ = respiration quotient.

fill, increased laxation, decreased transit time, and increased feed intake to compensate for the reduced dietary energy obtained through the consumption of dietary fiber (Kyriazakis and Emmans, 1995). The decrease in transit time may have reduced the amount of time the microbial population in the hindgut of the pig had to ferment the fiber in wheat bran, which may be the reason for the reduction in the synthesis of CH_4 that was observed in the current experiment as wheat bran inclusion increased. In vitro total tract digestibility of DM and nonstarch polysaccharides in wheat bran is 63.6 and 20.6%, respectively (Jaworski et al., 2015), indicating that the fiber in wheat bran has a low fermentability, which may also have contributed to the reduction in CH_4 excretion that was observed as inclusion of wheat bran increased.

Pigs fed diets containing greater amounts of dietary fiber in the form of wheat bran have an increased empty weight of the gastrointestinal tract compared with pigs fed a wheat-based diet that is lower in fiber (Kyriazakis and Emmans, 1995). The gastrointestinal tract of animals may account for as much as 30% of FHP and when the size of the tract is increased, the energy required to maintain the tract increases; therefore, the FHP or NE required for maintenance is increased (Baldwin, 1995). However, in the present experiment, FHP and fasting RQ of pigs were not different among pigs that were previously fed different experimental diets. The relatively short duration of feeding the experimental diets may have limited the expansion of the gastrointestinal tract, which likely is the reason FHP was not different among

Table 4. Apparent total tract digestibility (ATTD) of nutrients and energy by growing pigs fed experimental diets (as-fed basis)

	Diet				*P*-value	
ATTD, %	Basal	15% Wheat bran	30% Wheat bran	Pooled SEM	Linear	Quadratic
DM	91.74	86.09	81.62	0.60	<0.01	0.40
CP	91.20	87.73	83.87	0.65	<0.01	0.80
GE	91.92	85.78	81.13	0.55	<0.01	0.25
Crude fiber	69.54	54.93	39.32	6.43	<0.01	0.93
ADF	79.60	61.30	52.22	2.55	<0.01	0.05
NDF	74.17	65.42	64.71	2.29	<0.01	0.10

treatments. The FHP obtained in this experiment is within the range of values for FHP obtained in similar experiments conducted in the same facility (Liu et al., 2014; Zhang et al., 2014), and the FHP obtained in this experiment was close to the value for FHP reported by Noblet et al. (1994) and by the NRC (2012).

Daily retained energy by pigs linearly decreased ($P \leq 0.05$) from 266.87 to 223.85 and 216.28 kcal/kg $BW^{0.6}$ as pigs were fed diets containing increasing amounts of wheat bran. The daily retained energy in pigs fed the basal diet or the 30% wheat bran diet was greater compared with previous work (Stewart et al., 2013). However, the results obtained by Stewart et al. (2013) were determined using the comparative slaughter method, and it has been suggested that the comparative slaughter method may underestimate energy retention of pigs compared with indirect calorimetry (Quiniou et al., 1995; Kil et al., 2011, 2013a,b). Retained protein did not differ among pigs fed experimental diets, which was most likely due to the fact that all diets were formulated to meet or exceed NRC (2012) requirements for standardized ileal digestible indispensable AA; therefore, protein synthesis was not limited in this experiment. However, retained lipid linearly decreased ($P \leq 0.05$) when pigs were fed increasing amounts of wheat bran, which was a result of the decreased ATTD of nutrients and energy and the reduced DE, ME, and NE in the diets as wheat bran inclusion increased. These results indicate lower rates of lipid deposition by pigs fed increased concentrations of wheat bran, which also may contribute to the lower HP that was observed as wheat bran inclusion increased in diets.

The NE in the experimental diets linearly decreased ($P \leq 0.05$) from 1,808 to 1,575 and 1,458 kcal/kg as wheat bran inclusion increased. A diet containing 30% wheat middlings and fed to growing pigs was determined to contain 1,759 kcal NE/kg (Stewart et al., 2013), which is slightly greater than the NE in the 30% wheat bran diet used in the current experiment, but wheat bran also contains less DE, ME, and NE than wheat middlings (NRC, 2012). The NE in the corn–soybean meal basal diet used in this experiment (1,808 kcal/kg) is in agreement with a recent estimate (1,870 kcal/kg) for a similar diet (Kil et al., 2013b).

Linear regression analyses were used to examine the relationship between energy and dietary wheat bran according to Young et al. (1977) and Noblet et al. (1993). The dependent variable in the 3 prediction equations was dietary DE, ME, or NE in kilocalories per kilogram (as-fed basis), respectively and the independent variable was dietary wheat bran inclusion in percent (as-fed basis; Table 5). The prediction equation for dietary DE had an intercept equal to 3,457.7 ($P \leq 0.05$) and a slope estimate of −11.725 ($P \leq 0.05$) with 90% of the variation in dietary DE explained by the model. The prediction equation for dietary ME had an intercept equal to 3,389.6 ($P \leq 0.05$) and a slope estimate of −11.725 ($P \leq 0.05$) with 92% of the variation in dietary ME explained by the model. The prediction equation for dietary NE had an intercept equal to 1,788.1 ($P \leq 0.05$) and a slope estimate of −8.273 ($P \leq 0.05$), but with only 35% of the variation in dietary NE explained by the model. The poor prediction of NE was because a large SEM was attributed to the NE in diets. The y-intercept of the 3 prediction equations is equal to the DE, ME, and NE in the basal diet (kcal/kg, as-fed basis). The slope of the prediction equations for DE and ME were the same, which indicates that the percent change in wheat bran inclusion produces the same decrease in DE as in ME. The DE, ME, and NE in wheat bran estimated using the prediction equations were 2,285, 2,217, and 961 kcal/kg (as-fed basis), respectively (Table 6).

Table 5. Regression coefficients used for estimating DE, ME, and NE in wheat bran (as-fed basis)[1]

		SE		*P*-value			
Dependent variable	Prediction equation	Intercept	Estimate	Intercept	Estimate	R^2	RMSE[2]
Dietary DE, kcal/kg	3,457.7 − 11.725 × (wheat bran inclusion, %)	18.27	0.98	<0.001	<0.001	0.90	48.87
Dietary ME, kcal/kg	3,389.6 − 11.725 × (wheat bran inclusion, %)	17.09	0.92	<0.001	<0.001	0.92	45.70
Dietary NE, kcal/kg	1,788.1 − 8.273 × (wheat bran inclusion, %)	54.55	2.94	<0.001	0.013	0.35	145.89

[1]Data were subjected to linear regression analysis with the percent inclusion of wheat bran as the independent variable and the kilocalories per kilogram DE, ME, or NE of the diet as the dependent variable. The regression coefficients indicate the change in the DE, ME, or NE of the diets for each percentage point change of wheat bran included in the diet; therefore, the coefficient multiplied by 100 is equal to the DE, ME, or NE in wheat bran.

[2]RMSE = root mean square error.

The DE, ME, and NE in wheat bran determined using the difference method were 2,168, 2,117, and 896 kcal/kg (as-fed basis), respectively. In agreement with our hypothesis and data reported by Bolarinwa and Adeola (2012), the DE, ME, and NE in wheat bran obtained using the difference procedure were within the 95% confidence intervals obtained for the DE, ME, and NE in wheat bran estimated using linear regression. This indicates that the 2 procedures estimate values for DE, ME, and NE that are not different. The NE in wheat middlings was recently reported at 987 kcal/kg (Stewart et al., 2013), which is slightly greater than the NE in wheat bran obtained using either method in the current experiment. The reason for this difference is most likely that the wheat bran used in this experiment contained more dietary fiber and less starch compared with the wheat middlings used in the experiment by Stewart et al. (2013). The NE that was calculated for wheat bran in this experiment is also less than the current value published by NRC (2012). This can also partly be explained by the reduced concentration of starch and the increased concentration of fiber in the wheat bran fed in this experiment. However, it is also possible that the value published by NRC (2012) overestimates the NE, but further research is needed to confirm this hypothesis.

Table 6. Energy concentration in wheat bran determined using the difference procedure or estimated from the regression procedure

Item	Method		95% Confidence interval
	Difference procedure[1]	Regression procedure	
As-fed basis			
DE, kcal/kg	2,168	2,285	2,036–2,534
ME, kcal/kg	2,117	2,217	1,984–2,450
NE, kcal/kg	896	961	218–1,704
DM basis			
DE, kcal/kg	2,478	2,611	2,327–2,896
ME, kcal/kg	2,419	2,534	2,267–2,800
NE, kcal/kg	1,024	1,098	249–1,947

[1]The values presented are the mean DE, ME, and NE in wheat bran calculated using the difference procedure for the 2 diets containing 15 or 30% wheat bran.

Conclusion

Inclusion of 0, 15, or 30% wheat bran in diets fed to growing pigs resulted in a decreased ATTD of nutrients and energy as wheat bran inclusion increased, which led to a decrease in dietary DE, ME, and NE. The HP of pigs linearly decreased as dietary wheat bran inclusion increased, but FHP of pigs was unaffected by inclusion of wheat bran in the diets. The excretion of CH_4 decreased as wheat bran inclusion increased, indicating that the fermentation of wheat bran is low due to the large concentration of insoluble dietary fiber. The DE, ME, and NE in wheat bran determined using the difference procedure were in good agreement with the DE, ME, and NE estimated using linear regression, indicating that both procedures may be used to estimate energy values in feed ingredients.

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