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Effects of dietary soybean hulls and wheat middlings on body composition, nutrient and energy retention, and the net energy of diets and ingredients fed to growing and finishing pigs[1]

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ABSTRACT: The objectives of this experiment were 1) to determine the effect of dietary soybean hulls (SBH) and wheat middlings (WM) on body composition, nutrient and energy retention, and the NE of diets and ingredients fed to growing or finishing pigs and 2) to determine if finishing pigs use the energy in SBH and WM more efficiently than growing pigs. Forty growing barrows (initial BW: 25.4 ± 0.7 kg) and 40 finishing barrows (initial BW: 84.8 ± 0.9 kg) were randomly allotted to 5 groups within each stage of growth. Two groups at each stage of growth served as the initial slaughter group. The remaining pigs were randomly assigned to 3 dietary treatments and harvested at the conclusion of the experiment. The basal diet was based on corn and soybean meal and was formulated to be adequate in all nutrients. Two additional diets were formulated by mixing 70% of the basal diet and 30% SBH or 30% WM. In the growing phase, ADG, G:F, and retention of lipids were greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the diets containing SBH or WM. Retention of energy was also greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the SBH. In the finishing phase, pigs fed the SBH diet tended ($P = 0.10$) to have a greater ADG than pigs fed the WM diet, and energy retention was greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the WM diet. The NE of the basal diet fed to growing pigs was greater ($P < 0.01$) than the NE of the diets containing SBH or WM, and there was a tendency for a greater ($P = 0.05$) NE of the basal diet than of the other diets when fed to finishing pigs. The NE of SBH did not differ from the NE of WM in either growing or finishing pigs, and there was no interaction between ingredients and stage of growth on the NE of diets or ingredients. The NE of diets for growing pigs (1,668 kcal/kg) was not different from the NE of diets for finishing pigs (1,823 kcal/kg), and the NE of the diets containing SBH (1,688 kcal/kg) was not different from the NE of the diets containing WM (1,803 kcal/kg). Likewise, the NE of SBH (603 kcal/kg) did not differ from the NE of WM (987 kcal/kg). In conclusion, inclusion of 30% SBH or WM decreases the performance and nutrient retention in growing pigs but has little impact on finishing pigs. The NE of the diets decreases with the inclusion of SBH and WM, but the NE of diets and ingredients is not affected by the BW of pigs. The NE of SBH is not different from the NE of WM.

Key words: energy retention, net energy, performance, pig, soybean hulls, wheat middlings

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INTRODUCTION

Use of highly fibrous ingredients has been limited in diets fed to pigs because the energy and nutritional values of fibrous ingredients and their impact on growth performance and body energy in pigs are not well understood. However, both soybean hulls (**SBH**) and wheat middlings (**WM**) are produced in the United States in relatively great quantities, and a more accurate assessment of the energy value of these ingredients may result in increased use.

In North America, the energy concentration of swine diets is most often calculated on the basis of the DE and ME of ingredients. However, DE and ME values may overestimate the energy concentration of fibrous ingredients because DE and ME values do not account for the heat increment when these ingredients are fermented by pigs (Noblet et al., 1994a). On the other hand, the NE system accounts for the energy lost as heat increment, and therefore, NE values are believed to more accurately reflect the energy value of fibrous ingredients than DE and ME values (Noblet et al., 1994a).

Finishing pigs may have a greater capacity to use fiber in the diets than growing pigs (Noblet and Shi, 1994; Noblet et al., 1994b; Wu et al., 2007) because they have greater microbial activity in the hind gut (Just, 1983; Shi and Noblet, 1994). Finishing pigs also have a greater capacity for lipid gain than growing pigs (de Greef et al., 1994), and the absorbed end products from fermentation (i.e., VFA) have a greater efficiency for lipid deposition (62%) than for ATP synthesis (50%; Black, 1995).

Therefore, we hypothesized that the NE of fibrous ingredients is greater in finishing pigs than in growing pigs. The primary objectives of this research were 1) to calculate the NE of SBH and WM in both growing and finishing pigs by determining body composition and retention of protein, lipids, and energy in growing and finishing pigs fed diets without or with SBH or WM and 2) to compare NE values of diets and fibrous ingredients between growing and finishing pigs.

MATERIALS AND METHODS

The experiment was approved by the Institutional Animal Care and Use Committee at the University of Illinois.

Animals, Housing, and Experimental Design

Forty growing and 40 finishing barrows originating from the matings of line 337 boars to C 22 females (Pig Improvement Company, Hendersonville, TN) were used. The average initial BW of the pigs were 25.4 ± 0.7 and 84.8 ± 0.9 kg for the growing and finishing pigs, respectively. All pigs used in the experiment were selected on the basis of BW and ADG during the 2 wk preceding the experiment; only animals that had ADG within ±20% of the average during the preceding 2 wk were used in the experiment. Within each stage of growth, pigs were randomly allotted to 5 groups according to BW with 8 pigs per group. All pigs in 2 groups ($n = 16$) at each stage of growth served as the initial slaughter group and were harvested at the start of the experiment. The other 3 groups were randomly assigned to 3 dietary treatments, and all pigs from these groups were harvested at the conclusion of the experiment. The experimental period was 28 d for growing pigs and 35 d for finishing pigs. All pigs were housed in an environmentally controlled building with the average ambient temperature being maintained at 24°C and 18°C for growing and finishing pigs, respectively. Pigs were housed individually in 0.9 × 1.8 m pens that were equipped with a feeder, a nipple drinker, and a fully slatted concrete floor.

Table 1. Analyzed chemical composition of soybean hulls and wheat middlings (as-fed basis)

Composition	Soybean hulls	Wheat middlings
DM, %	88.90	89.94
GE, kcal/kg	3,704	4,094
CP, %	9.34	17.14
Ether extract, %	1.51	3.89
Acid-hydrolyzed ether extract, %	2.47	4.87
Crude fiber, %	36.17	9.23
Ash, %	4.18	5.12

Dietary Treatments

Commercial sources of corn, soybean meal, SBH, and WM were obtained locally, and the same batch of these ingredients was used to formulate all diets (Table 1). Three diets at each stage of growth were formulated (Table 2). The basal diet contained corn and soybean meal. Vitamins and minerals were included in the basal diet to exceed estimated nutrient requirements (NRC, 1998) of pigs at each stage of growth. Chromic oxide (0.50%) was included in the basal diet as an indigestible marker. Two additional diets were formulated by mixing 70% of the basal diet and 30% SBH or 30% WM (as-fed basis). No antibiotic growth promoters were used, and all diets were provided in a meal form. Pigs were allowed ad libitum access to feed and water during the entire experimental period. Because the substitution procedure was used to calculate the NE of SBH and WM and the DE and ME in SBH and WM are less than in the basal diet, it was not possible to formulate diets that were equal in DE and ME. However, all diets were formulated to be nutritionally adequate in all nutrients (NRC, 1998).

Table 2. Composition of experimental diets (as-fed basis)[1]

Item	Growing pigs			Finishing pigs		
	Basal	SBH	WM	Basal	SBH	WM
Ingredients, %						
Ground corn	62.62	43.83	43.83	78.96	55.27	55.27
Soybean meal, 47.5%	31.80	22.26	22.26	16.10	11.27	11.27
Soybean hulls	—	30.00	—	—	30.00	—
Wheat middlings	—	—	30.00	—	—	30.00
Soybean oil	2.00	1.40	1.40	2.00	1.40	1.40
Ground limestone	1.15	0.81	0.81	1.00	0.70	0.70
Monocalcium phosphate	1.22	0.85	0.85	0.73	0.51	0.51
Chromic oxide	0.50	0.35	0.35	0.50	0.35	0.35
Vitamins premix[2]	0.21	0.15	0.15	0.21	0.15	0.15
Minerals premix[3]	0.50	0.35	0.35	0.50	0.35	0.35
Total	100.00	100.00	100.00	100.00	100.00	100.00
Energy and nutrients, analyzed						
DM, %	88.30	88.19	88.66	87.87	87.88	88.98
GE, Mcal/kg	3.90	3.90	3.99	3.95	3.89	3.97
CP, %	21.21	17.83	20.30	14.37	12.44	15.21
Ether extract, %	4.38	3.36	3.82	4.55	3.43	4.10
AEE,[4] %	5.53	4.50	5.51	5.65	4.35	5.44
Crude fiber, %	2.01	12.43	3.73	1.79	11.61	3.65
Ash, %	6.09	5.28	5.76	4.28	4.21	4.78
Energy and nutrients, calculated[5]						
ME, Mcal/kg	3.38	2.97	3.28	3.41	2.99	3.30
Total Lys, %	1.12	1.05	0.96	0.69	0.75	0.66
Ca, %	0.77	0.73	0.58	0.58	0.60	0.44
Bioavailable P, %	0.28	0.21	0.31	0.18	0.14	0.24

[1]Basal = basal diet; SBH = diet containing 30% soybean hulls; WM = diet containing 30% wheat middlings.

[2]Vitamin premix provided these quantities of vitamins per kilogram of the complete basal diet: vitamin A, 6,608 IU; vitamin D_3, 680 IU; DL-α-tocopheryl acetate, 88 mg; menadione sodium bisulfite complex, 4 mg; riboflavin, 9 mg; vitamin B_{12}, 35 μg; D-Ca-pantothenic acid, 24 mg; niacin, 33 mg; and choline chloride, 324 mg.

[3]Mineral premix provided these quantities of mineral per kilogram of the complete basal diet: Fe, 90 mg as ferrous sulfate; Zn, 100 mg as zinc oxide; Mn, 20 mg as manganese oxide; Cu, 8 mg as copper sulfate; I, 0.35 mg as potassium iodide; Se, 0.3 mg as sodium selenite; and NaCl, 3 g.

[4]AEE = acid-hydrolyzed ether extract.

[5]Values calculated from NRC (1998).

Sample Collection, Chemical Analyses, and Data Calculation

The procedures for slaughtering pigs, collecting and analyzing samples, and calculating growth performance, apparent total tract digestibility (**ATTD**) of nutrients, carcass composition, retention of protein, lipids, and energy, and NE of diets and ingredients were similar to those described by Kil (2008) and Kil et al. (2011). For the slaughter procedure, in short, pigs were stunned by a hog stunner (Best & Donovan, Cincinnati, OH), and care was taken to ensure that all blood was collected. All carcasses were split down the midline from the groin to the chest cavity. The visceral organs were removed, and the weight was recorded. The gastrointestinal tract was separated from the other organs and was flushed with water to remove digesta. The emptied tract was patted dry, and the empty gastrointestinal weight was recorded. All visceral organs were ground in a meat mincer (Butcher Boy; Lasar Manufacturing Company, Los Angeles, CA), and subsamples were collected. Subsamples were further ground using a food processor (Proctor Silex, Hamilton Beach, CA), lyophilized, and then ground again before chemical analyses.

The carcasses were stored in a 4°C cooler for 16 h, and the chilled weight was recorded. The carcasses were cut into pieces to fit the grinding apparatus (Autio Company, Astoria, OR). Carcasses of the growing pigs were ground twice using a 12-mm-diam. die and approximately, 5 kg of the ground carcass were collected and stored at –20°C. The carcasses of the finishing pigs were ground twice using an 18-mm-diam. die, and approximately 8 kg of the ground carcass were collected and stored at –20°C. The frozen samples were then thawed in a cooler at 4°C for 16 h and cut into half-inch slices of carcass using a band saw (Hobart Company, Troy, OH). These carcass slices were ground twice through a meat grinder (Butcher Boy; Lasar Manufacturing Company) using a 2-mm die. The subsamples of carcasses were collected, lyophilized, and ground again before chemical analyses.

For the calculation of energy, protein, and lipid retention, the initial quantities of energy, protein, and lipids in pigs, as calculated from the sum of the energy, protein, and lipids in the blood, viscera, and carcass, were determined from the initial slaughter group, and the final quantities of energy, protein, and lipids in pigs were determined from pigs fed the treatment diets. The composition of each of the pigs on the 3 treatment groups at the start of the experiment was predicted on the basis of the body composition and the BW of the pigs in the initial slaughter group. The difference between the initial quantity and the final quantity of energy, protein, and lipids was considered the total quantity of energy, protein, and lipids retained during the entire experimental period. The NE value for each diet was calculated from the sum of energy retention and the total quantity of the energy used for NE_m (Ewan, 2001). The daily NE_m for each pig was calculated by multiplying the mean metabolic BW ($kg^{0.6}$) during the experimental period by 179 kcal for both growing and finishing pigs (Noblet et al., 1994a). The total NE_m was calculated by multiplying the calculated daily NE_m for each pig by the number of days pigs were fed the experimental diets (i.e., 28 d for growing pigs and 35 d for finishing pigs). The NE of SBH and WM was subsequently calculated using the difference procedure (de Goey and Ewan, 1975).

Statistical Analyses

All data were analyzed by ANOVA using the MIXED procedure (SAS Inst. Inc., Cary, NC) with the pig as the experimental unit. Homogeneity of the variances was verified using the UNIVARIATE procedure of SAS. The residual vs. the predicted plot procedure was used to analyze for outliers, but no data were determined to be outliers. Within each stage of growth, the model included dietary treatment as the fixed effect. The LSMEANS procedure was used to calculate mean values, and the PDIFF option was used to separate means. The interactions between fibrous ingredients and stage of growth on the NE of diets or ingredients were also analyzed. The model included dietary treatments, stage of growth, and their interactions as the fixed effects. However, the interactions were not significant for the NE of diets and ingredients, and therefore, the interaction term was omitted in the final analysis. An α value of 0.05 was used to assess significance among means, and $0.05 \leq P \leq 0.10$ was considered a tendency.

RESULTS

Pig Performance and Nutrient Digestibility

In the growing phase, final BW, ADG, and G:F for pigs fed the diets containing SBH or WM were less ($P < 0.05$) than for pigs fed the basal diet, but there were no differences between pigs fed the diet containing SBH and WM (Table 3). There was no difference in ADFI among dietary treatments, and the ATTD of energy, CP, and acid-hydrolyzed ether extract were not affected by dietary treatments. In the finishing phase, there was a trend for pigs fed the SBH diet to have a greater final BW ($P = 0.07$) and greater ADG ($P = 0.10$) than pigs fed the WM diet, whereas pigs fed the basal diet had final BW and ADG that were not different from values obtained for pigs fed the other diets. No differences in ADFI or G:F were observed among dietary treatments. Pigs fed the diets containing SBH or WM had less ($P < 0.05$) ATTD of energy than pigs fed the basal diet. Pigs fed the diet containing SBH had less ($P < 0.05$) ATTD of CP compared with pigs fed the basal diet or the diet containing WM.

Table 3. Growth performance and apparent total tract digestibility (ATTD) of energy and nutrients of growing and finishing pigs fed the basal diet or the diets containing soybean hulls (SBH) or wheat middlings (WM)[1]

	Dietary treatment[2]				
Item	Basal	SBH	WM	SEM	*P*-value[3]
Growing pigs					
Initial BW, kg	24.51	25.44	25.68	0.41	0.13
Final BW, kg	56.69^{y}	52.56^{x}	50.69^{x}	1.13	<0.01
ADG, kg	1.15^{y}	0.97^{x}	0.89^{x}	0.04	<0.01
ADFI, kg	2.08	2.05	1.85	0.10	0.23
G:F, kg/kg	0.56^{y}	0.48^{x}	0.48^{x}	0.03	<0.05
ATTD, %					
Energy	71.7	68.7	70.6	3.8	0.86
CP	73.9	68.3	72.4	3.0	0.42
AEE[4]	52.8	56.9	54.9	5.3	0.86
Finishing pigs					
Initial BW, kg	85.70	84.10	84.13	1.25	0.59
Final BW, kg	126.48^{ab}	126.95^{b}	121.25^{a}	1.80	0.07
ADG, kg	1.17^{ab}	1.22^{b}	1.06^{a}	0.05	0.10
ADFI, kg	3.19	3.41	3.12	0.13	0.30
G:F, kg/kg	0.37	0.36	0.34	0.02	0.53
ATTD, %					
Energy	78.5^{y}	68.7^{x}	68.3^{x}	2.0	<0.01
CP	71.5^{y}	54.0^{x}	66.0^{y}	2.6	<0.01
AEE[4]	43.6	35.5	40.8	4.7	0.48

^{x,y}Means within a row lacking a common superscript letter are different ($P < 0.05$).

^{a,b}Means within a row lacking a common superscript letter tend to be different ($0.05 \leq P \leq 0.10$).

[1]Data are least squares means of 8 observations per treatment.

[2]Basal = basal diet; SBH = diet containing 30% soybean hulls; WM = diet containing 30% wheat middlings.

[3]*P*-value for diet is based on ANOVA.

[4]AEE = acid-hydrolyzed ether extract.

Carcass Composition

In the growing phase, BW, HCW, dressing percentage, chilled carcass weight, and total digesta-free BW were greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the diets containing SBH or WM (Table 4). Pigs fed the diet containing SBH tended ($P = 0.07$) to have a greater full viscera weight than pigs fed the basal diet, and the per-

Table 4. Carcass composition and weights of body components of growing and finishing pigs fed the basal diet or the diets containing soybean hulls (SBH) or wheat middlings (WM)[1,2]

Item	ISG[3]	Dietary treatment[4]			SEM	P-value[5]
		Basal	SBH	WM		
Growing pigs						
Live BW, kg	24.0	51.5[y]	46.3[x]	45.9[x]	1.1	<0.01
HCW, kg	19.1	41.8[y]	36.0[x]	36.2[x]	0.9	<0.01
Dressing percentage, %	79.5	81.2[y]	77.7[x]	78.8[x]	0.5	<0.01
Chilled carcass wt, kg	18.8	41.3[y]	35.6[x]	35.7[x]	0.9	<0.01
Full viscera wt, kg	4.0	7.40[a]	8.0[b]	7.4[ab]	0.2	0.07
Full viscera wt, % live wt	16.8	14.4[x]	17.4[y]	16.2[y]	0.4	<0.01
Empty viscera wt, kg	2.0	3.6	3.6	3.7	0.1	0.84
Empty viscera wt, % live BW	8.4	6.9[x]	7.8[y]	8.0[y]	0.3	0.01
DF BW,[6] kg	21.5	47.0[y]	41.2[x]	41.4[x]	1.0	<0.01
Finishing pigs						
Live BW, kg	80.9	121.8[b]	121.0[ab]	116.6[a]	1.7	0.08
HCW, kg	67.1	103.5[y]	98.9[x]	97.9[x]	1.5	0.04
Dressing percentage, %	82.9	85.0[y]	81.7[x]	84.0[y]	0.6	<0.01
Chilled carcass wt, kg	66.4	102.7[y]	99.6[xy]	97.1[x]	1.4	0.04
Full viscera wt, kg	10.3	13.4[x]	16.3[y]	14.2[x]	0.5	<0.01
Full viscera wt, % live BW	12.8	11.1[x]	13.5[z]	12.2[y]	0.3	<0.01
Empty viscera wt, kg	8.6	11.2	11.7	11.1	0.3	0.26
Empty viscera wt, % live BW	10.6	9.2	9.7	9.5	0.2	0.22
DF BW,[6] kg	78.3	118.6[b]	116.7[ab]	112.8[a]	1.6	0.05

[x–z]Means within a row lacking a common superscript letter are different ($P < 0.05$).

[a,b]Means within a row lacking a common superscript letter tend to be different ($0.05 \leq P \leq 0.10$).

[1]Data are least squares means.

[2]$n = 16$ for initial slaughter group; $n = 8$ for all other treatments.

[3]ISG = initial slaughter group.

[4]Basal = basal diet; SBH = diet containing 30% soybean hulls; WM = diet containing 30% wheat middlings.

[5]*P*-value for diet is based on ANOVA.

[6]DF BW = digesta-free BW, which was the sum of the weight of chilled carcass, empty viscera, and blood.

centage weight of full or empty viscera relative to BW was less ($P < 0.05$) for pigs fed the basal diet than for pigs fed the diets containing SBH or WM.

In the finishing phase, there was a tendency ($P = 0.08$) for pigs fed the basal diet to have a greater BW than pigs fed the diet containing WM. The HCW was greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the diets containing SBH or WM. The dressing percentage was less ($P < 0.05$) for pigs fed the diet containing SBH than for pigs fed the basal diet or the diet containing WM. Chilled carcass weight was less ($P < 0.05$) for pigs fed the diet containing WM than for pigs fed the basal diet, but the full viscera weight for pigs fed the diet containing SBH was greater ($P < 0.05$) than for pigs fed the basal diet or the diet containing WM. The percentage weight of full viscera relative to BW was greatest ($P < 0.01$) for pigs fed the diet containing SBH but least ($P < 0.05$) for pigs fed the basal diet. Total digesta-free BW tended ($P = 0.05$) to be greater for pigs fed the basal diet than for pigs fed the diet containing WM.

Retention of Protein, Lipids, and Energy

In the growing phase, pigs fed the basal diet had greater ($P < 0.05$) carcass DM weight and lipid concentration in carcass DM than pigs fed the diets containing SBH or WM (Table 5). The energy concentration in carcass DM was greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the diet containing SBH. Viscera DM weight was not different among dietary treatments, but protein concentration in viscera DM was greater ($P < 0.05$) for pigs fed the diet containing SBH than for pigs fed the basal diet or the diet containing WM. The lipid and energy concentrations in viscera DM were less ($P < 0.05$) for pigs fed the diet containing SBH than for pigs fed the basal diet or the diet containing WM. The weight of total digesta-free body DM, the concentration of lipids in digesta-free body DM, and the total amounts of protein, lipids, and energy were greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the diets containing SBH or WM. The energy concentration in total digesta-free body DM was also greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the diet containing SBH, and pigs fed the basal diet had greater ($P < 0.05$) protein gain, lipid gain, and energy retention than pigs fed the diets containing SBH or WM.

Table 5. Retention of energy, protein, and lipids in growing pigs fed the basal diet or the diets containing soybean hulls (SBH) or wheat middlings (WM)[1,2]

		Dietary treatment[4]				
Item	ISG[3]	Basal	SBH	WM	SEM	P-value[5]
Carcass						
Carcass DM, kg	5.54	16.08^{y}	12.43^{x}	12.29^{x}	0.51	<0.01
Protein, g/kg	574	585	586	576	22	0.94
Lipids, g/kg	296	389^{y}	333^{x}	350^{x}	12	<0.01
Energy, Mcal/kg	5.98	6.32^{y}	6.05^{x}	6.20^{xy}	0.06	0.02
Viscera						
Viscera DM, kg	0.42	0.85	0.79	0.85	0.03	0.24
Protein, g/kg	657	580^{x}	621^{y}	583^{x}	8	<0.01
Lipids, g/kg	173	225^{y}	185^{x}	218^{y}	8	<0.01
Energy, Mcal/kg	5.65	5.91^{y}	5.67^{x}	5.83^{y}	0.05	<0.01
Blood						
Blood DM, kg	0.13	0.38	0.36	0.37	0.02	0.52
Protein, g/kg	959	901	900	900	2	0.85
Lipids, g/kg	7	2	2	3	0	0.88
Energy, Mcal/kg	5.49	5.31	5.29	5.30	0.01	0.68
Total DF body[6]						
DF BW, kg DM	6.09	17.32^{y}	13.58^{x}	13.52^{x}	0.53	<0.01
Protein, g/kg	588	592	597	585	21	0.93
Lipids, g/kg	281	372^{y}	316^{x}	332^{x}	11	<0.01
Energy, Mcal/kg	5.95	6.28^{y}	6.00^{x}	6.15^{xy}	0.08	0.01
Total protein, kg/pig	3.58	10.27^{y}	8.12^{x}	7.91^{x}	0.49	<0.01
Total lipids, kg/pig	1.72	6.47^{y}	4.31^{x}	4.48^{x}	0.28	<0.01
Total energy, Mcal/pig	36.31	108.82^{y}	81.61^{x}	83.18^{x}	3.60	<0.01
Protein gain, g/d	—	245^{y}	163^{x}	154^{x}	18	<0.01
Lipid gain, g/d	—	172^{y}	93^{x}	98^{x}	10	<0.01
Lipid gain:protein gain, g/g	—	0.74	0.58	0.66	0.06	0.24

[x,y]Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means.

[2]$n = 16$ for initial slaughter group; $n = 8$ for all other treatments.

[3]ISG = initial slaughter group.

[4]Basal = basal diet; SBH = diet containing 30% soybean hulls; WM = diet containing 30% wheat middlings.

[5]P-value for diet is based on ANOVA.

[6]Total DF body = total digesta-free body, which includes chilled carcass, empty viscera, and blood. DF BW = the sum of the weight of chilled carcass, empty viscera, and blood.

In the finishing phase, carcass DM weight was greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the diet containing WM (Table 6). Protein concentration in carcass DM was lower ($P < 0.05$) for pigs fed the basal diet than for pigs fed the diets containing SBH or WM, and the protein concentration in viscera DM was greatest ($P < 0.05$) for pigs fed the diet containing WM but lowest ($P < 0.05$) for pigs fed the basal diet. The weight of total digesta-free body DM was greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the diet containing WM. The concentration of protein in total digesta-free body DM was lower ($P < 0.05$) for pigs fed the basal diet than for pigs fed the diets containing SBH or WM, but the total amount of energy in the pig was greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the diet containing WM. Protein gain and lipid gain were not affected by dietary treatments, but the lipid gain:protein gain tended ($P = 0.08$) to be greater for pigs fed the basal diet than for pigs fed the diet containing WM.

Net Energy of Diets and Ingredients

In the growing phase, final body energy, energy retention, total NE_m, and NE intake were greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the diets containing SBH or WM, but there were no differences between pigs fed the diet containing SBH and pigs fed the diet containing WM (Table 7). The NE of the basal diet (2,101 kcal/kg) was greater ($P < 0.05$) than the NE of the diets containing SBH (1,577 kcal/kg) or WM (1,759 kcal/kg), but the NE of the diet containing SBH was not different from the NE of the diet containing WM. Likewise, the NE of SBH (354 kcal/kg) was not different from the NE of WM (959 kcal/kg).

In the finishing phase, final body energy, energy retention, and NE intake were greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the diet containing WM, but pigs fed the diet containing SBH had final body energy, energy retention, and NE intake that were not different from

Table 6. Retention of energy, protein, and lipids in finishing pigs fed the basal diet or the diets containing soybean hulls (SBH) or wheat middlings (WM)[1,2]

Item	ISG[3]	Dietary treatment[4] Basal	SBH	WM	SEM	P-value[5]
Carcass						
Carcass DM, kg	27.96	45.24[y]	41.59[xy]	39.84[x]	1.28	0.02
Protein, g/kg	388	311[x]	347[y]	350[y]	11	<0.05
Lipids, g/kg	495	558	554	549	13	0.88
Energy, Mcal/kg	7.00	7.29	7.12	7.13	0.08	0.26
Viscera						
Viscera DM, kg	2.53	3.61	3.78	3.55	0.16	0.59
Protein, g/kg	456	402[x]	448[y]	494[z]	13	<0.01
Lipids, g/kg	444	492	478	473	13	0.54
Energy, Mcal/kg	6.87	7.17	7.11	7.05	0.07	0.47
Blood						
Blood DM, kg	0.66	0.88	0.96	0.86	0.05	0.42
Protein, g/kg	971	895[ab]	894[a]	912[b]	9	0.07
Lipids, g/kg	5	3	3	4	0	0.40
Energy, Mcal/kg	5.51	5.27	5.27	5.32	0.02	0.15
Total DF body[6]						
DF BW DM, kg	31.14	49.73[y]	46.32[xy]	44.24[x]	1.30	0.02
Protein, g/kg	406	328[x]	367[y]	372[y]	11	0.02
Lipids, g/kg	481	543	536	532	12	0.81
Energy, Mcal/kg	6.96	7.25	7.08	7.09	0.08	0.25
Total protein, kg/pig	12.65	16.25	16.98	16.39	0.50	0.57
Total lipids, kg/pig	14.96	27.12	24.84	23.65	1.13	0.11
Total energy, Mcal/pig	216.6	361.2[y]	328.2[xy]	314.5[x]	11.9	0.03
Protein gain, g/d	—	100	127	111	14	0.40
Lipid gain, g/d	—	345	287	253	30	0.12
Lipid gain:protein gain, g/g	—	4.36[b]	2.58[ab]	2.35[a]	0.65	0.08

[x–z]Means within a row lacking a common superscript letter are different ($P < 0.05$).

[a,b]Means within a row lacking a common superscript letter tend to be different ($0.05 \leq P \leq 0.10$).

[1]Data are least squares means.

[2]$n = 16$ for initial slaughter group; $n = 8$ for all other treatments.

[3]ISG = initial slaughter group.

[4]Basal = basal diet; SBH = diet containing 30% soybean hulls; WM = diet containing 30% wheat middlings.

[5]*P*-value for diet is based on ANOVA.

[6]Total DF body = total digesta-free body, which includes chilled carcass, empty viscera, and blood. DF BW = the sum of the weight of chilled carcass, empty viscera, and blood.

those of pigs fed the other diets. However, total NE_m was greater ($P < 0.05$) for pigs fed the basal diet than for pigs fed the diet containing SBH but not different from that of pigs fed the diet containing WM. The NE of the basal diet (2,204 kcal/kg) tended ($P = 0.05$) to be greater ($P < 0.05$) than the NE of the diets containing SBH (1,799 kcal/kg) or WM (1,847 kcal/kg), but the NE of the diet containing SBH was not different from the NE of the diet containing WM, and the NE of SBH (852 kcal/kg) was not different from the NE of WM (1,015 kcal/kg).

No interactions between ingredients and stage of growth were observed for the NE of diets containing SBH or WM and for the NE of ingredients, and therefore, the main effects of ingredients and stage of growth on the NE of diets containing SBH or WM and of each ingredient were calculated (Table 8). The NE of the diet containing SBH (1,688 kcal/kg) was not different from the NE of the diet containing WM (1,803 kcal/kg), and no difference between the NE of SBH (603 kcal/kg) and WM (987 kcal/kg) was observed. The NE of diets containing SBH or WM was not different between growing pig (1,668 kcal/kg) and finishing pigs (1,823 kcal/kg), and the NE of ingredients did not differ between growing pigs (656 kcal/kg) and finishing pigs (934 kcal/kg).

DISCUSSION

Pig Performance and Nutrient Digestibility

The observation that inclusion of SBH or WM in the diets decreased ADG and G:F in growing pigs but not in finishing pigs confirms results of previous experiments (Shaw et al., 2002; Hinson et al., 2005). These results indicate that finishing pigs are more efficient in the use

Table 7. Net energy of diets and ingredients in growing and finishing pigs[1]

Item	Dietary treatment[2] Basal	SBH	WM	SEM	*P*-value[3]
Growing pigs					
Initial body energy,[4] Mcal	34.7	36.1	36.4	0.6	0.13
Final body energy, Mcal	108.8[y]	81.6[x]	83.2[x]	3.6	<0.01
Energy retention, Mcal	74.1[y]	45.6[x]	46.8[x]	3.6	<0.01
Total NE_m,[5] Mcal	46.1[y]	44.4[x]	43.8[x]	0.6	0.02
Total NE intake,[6] Mcal	120.2[y]	89.9[x]	90.6[x]	3.9	<0.01
Total feed intake, kg	58.2	57.4	51.9	2.8	0.23
NE of diets,[7] kcal/kg	2,101[y]	1,577[x]	1,759[x]	89	<0.01
NE of ingredients,[8] kcal/kg	—	354	959	255	0.12
Finishing pigs					
Initial body energy,[4] Mcal	218.3	214.2	214.3	3.2	0.59
Final body energy, Mcal	361.2[y]	328.2[xy]	314.5[x]	11.9	0.03
Energy retention, Mcal	142.9[y]	114.0[xy]	100.2[x]	11.0	0.04
Total NE_m,[5] Mcal	101.7[y]	98.3[x]	99.5[xy]	0.8	0.02
Total NE intake,[6] Mcal	244.6[y]	212.4[xy]	199.8[x]	11.4	0.03
Total feed intake, kg	111.7	119.4	109.3	4.7	0.30
NE of diets,[7] kcal/kg	2,204[a]	1,799[b]	1,847[b]	120	0.05
NE of ingredients,[8] kcal/kg	—	852	1015	411	0.78

[x,y]Means within a row lacking a common superscript letter are different ($P < 0.05$).

[a,b]Means within a row lacking a common superscript letter tend to be different ($0.05 \leq P \leq 0.10$).

[1]Data are least squares means of 8 observations per treatment for growing pigs and finishing pigs.

[2]Basal = basal diet; SBH = diet containing 30% soybean hulls; WM = diet containing 30% wheat middlings.

[3]*P*-value for diet is based on ANOVA.

[4]Initial energy was calculated by multiplying the initial BW of pigs by the energy concentration (Mcal/kg BW) of pigs in the initial slaughter groups. The average BW of pigs in the initial slaughter groups were 25.62 and 85.05 kg for growing and finishing pigs, respectively.

[5]Total NE_m was calculated by multiplying the mean metabolic BW ($kg^{0.6}$) of each pig by 179 kcal for growing and finishing pigs (Noblet et al., 1994a) and the number of days on experiment (28 d for growing pigs and 35 d for finishing pigs).

[6]Total NE intake = energy retention plus total NE_m.

[7]NE of the basal diet, the diet containing 30% SBH, or the diet containing 30% WM.

[8]The NE of SBH and WM were calculated using the difference procedure by subtracting the NE contribution from the basal diet from the NE of the diets containing 30% SBH or 30% WM (de Goey and Ewan, 1975).

of energy and nutrients in SBH and WM than growing pigs, which may be a result of a better use of end products of fermentation because the efficiency of using VFA for lipid synthesis is greater than using VFA for ATP synthesis (Black, 1995). Finishing pigs may also absorb more energy from high-fiber ingredients than growing pigs because they have a greater capacity for fiber fermentation in the hindgut (Noblet and Shi, 1994). It has been suggested that decreased energy concentration in the diets results in increased feed intake because pigs will attempt to meet a certain energy requirement by increasing feed consumption (Owen and Ridgeman, 1967, 1968; Frank et al., 1983). However, the results of the current experiment did not confirm this hypothesis, which is in agreement with Shaw et al. (2002) and Hinson et al. (2005), who also observed that feed intake did not change if WM or SBH was included in diets fed to growing or finishing pigs. The reason may be that the increased diet bulkiness that is a consequence of

Table 8. Net energy of the diets containing soybean hulls (SBH) or wheat middlings (WM) and net energy of SBH and WM as affected by the stage of growth[1]

	Ingredient		Stage of growth[2]			*P*-value[3]	
Item	SBH	WM	G	F	SEM	Ingredient	Stage
NE of diets,[4] kcal/kg	1,688	1,803	1,668	1,823	72	0.27	0.14
NE of ingredients,[5] kcal/kg	603	987	656	934	239	0.27	0.42

[1]Data are least squares means of 16 observations.

[2]Stage of growth = growing (G) and finishing (F).

[3]*P*-values for main effects of ingredient and stage of growth. No interactions between ingredient and stage of growth were observed for the NE of diets containing SBH or WM and NE of SBH or WM.

[4]NE of diets containing 30% SBH or 30% WM.

[5]NE of SBH or WM.

inclusion of fibrous ingredients in the diets increases gut fill, which restricts the ability of pigs to consume adequate amounts of diets to satisfy their energy requirements (Henry, 1985; Barnes et al., 2010). Pigs in the present experiment were kept in individual pens, and they had unlimited access to feed. The fact that the pigs fed the WM and SBH diets were unable to compensate for the lower energy concentration by increasing feed intake further indicates that diet bulkiness was limiting feed intake.

Carcass Composition and Retention of Energy, Protein, and Lipids

The decrease in dressing percentage that was observed for both growing and finishing pigs fed diets containing SBH or WM compared with pigs fed the basal diet agrees with observations from previous experiments (de Quadros et al., 2008; Barnes et al., 2010). Increased concentrations of fiber in the diets may increase the weight of visceral organs and gut fill of pigs (Kass et al., 1980; Henry, 1985; Pond et al., 1988), and the observation that the percentage weight of full viscera relative to BW in both growing and finishing pigs increased as SBH or WM was included in the diets agrees with this hypothesis. Therefore, it appears that increased weight of full viscera relative to BW by inclusion of SBH and WM is the primary reason for the decreased dressing percentage in growing and finishing pigs fed diets containing SBH or WM.

The decreased energy retention in both growing and finishing pigs fed diets containing SBH or WM compared with pigs fed the basal diet demonstrates that dietary SBH and WM provide less available energy to the pigs than corn and soybean meal. Dietary fiber decreases the absorption of energy because fibers are fermented in the hindgut, where the energy is absorbed in the form of VFA, which have less energetic efficiency than energy absorbed in the form of glucose in the small intestine (Just, 1982). The energy requirement of growing pigs may also have increased with inclusion of SBH or WM in the diets because of the increased weight of the visceral organ, which is the greatest energy-consuming organ in the body (Pond et al., 1988; van Milgen et al., 1998). Therefore, it can be speculated that in pigs fed diets containing SBH or WM, more energy was absorbed in the hindgut rather than in the small intestine, and a greater proportion of the absorbed energy was used for maintenance than for energy retention compared with pigs fed the basal diet. This also explains why diets containing SBH or WM decreased protein gain and lipid gain for growing pigs and tended to decrease lipid gain:protein gain for finishing pigs.

Net Energy of Diets and Ingredients

The values for the NE of each diet fed to growing or finishing pigs that were calculated in this experiment, in which the comparative slaughter procedure was used, are less than values that may be calculated from the NE of each ingredient (Sauvant et al., 2004). However, the values reported by Sauvant et al. (2004) were based on prediction equations obtained from determining heat production of different diets using indirect calorimetry and pigs that were not offered ad libitum access to feed. Similar observations were reported from previous experiments (Kil, 2008; Kil et al., 2011) and indicate that that NE values of diets calculated from the comparative slaughter procedure are less than values calculated according to Sauvant et al. (2004). These differences are likely caused by differences among experiments in methodologies used to determine NE values, and it is recognized that different methodologies may result in different estimates for NE values of ingredients (Kil et al., 2011). When using the comparative slaughter procedure, it is critical that a correct estimate for the initial body composition of pigs is used. In the present experiment, we attempted to increase the accuracy of this estimate by including 16 pigs in the initial slaughter group. We also included 8 pigs per treatment group, which is more than in most previous experiments in which the comparative slaughter procedure was used. In addition, pigs were allowed ad libitum access to feed in the present experiment because growing-finishing pigs fed under commercial conditions in the United States always are allowed ad libitum access to feed. However, pigs allowed ad libitum access to feed have reduced energy digestibility compared with pigs fed a restricted amount of feed (Chastanet et al., 2007), which may have contributed to the reduced NE values observed in this experiment compared with the values reported by Sauvant et al. (2004).

The decreased NE of diets containing SBH or WM compared with the basal diet agrees with previous data (Just, 1982) and is mainly a consequence of the reduced NE values for fibrous ingredients compared with those of corn and soybean meal. The NE of SBH for growing pigs that was calculated in this experiment is less than the NE of SBH reported by Sauvant et al. (2004), but the value for finishing pigs is close to the value presented by Sauvant et al. (2004). The NE values of WM for growing and finishing pigs that were calculated in this experiment agree with values reported by Pals and Ewan (1978) but are less than the NE of WM published by NRC (1998) and by Sauvant et al. (2004). The values reported by Pals and Ewan (1978) were calculated using the comparative slaughter procedure, as in this experiment, whereas the values reported by Sauvant et al. (2004) were calculated from indirect calorimetry and restrictedly fed pigs. This further indicates that methodologies used to calculate NE values may influence the NE values obtained.

Finishing pigs may have a greater capacity for using dietary fiber, and therefore, the NE of diets containing fibrous ingredients is expected to be greater for finishing pigs than for growing pigs (Just, 1983; Just et al., 1983; Noblet et al., 1994b; Shi and Noblet, 1994). Our previous experiments confirmed this observation (Kil, 2008; Kil et al., 2011). In the current experiment, inclusion of 30% SBH or WM decreased ADG and G:F in growing pigs but not in finishing pigs. We were, however, not able to detect a significant difference between growing and finishing pigs for the NE of diets or ingredients. Finishing pigs had numerically greater NE values than growing pigs, but because of relatively large SEM values associated with the calculated NE values, these differences were not significant.

In conclusion, results of the current experiment indicate that the NE of both SBH and WM is less than a corn–soybean meal diet, and the NE of diets will, therefore, be reduced if SBH or WM is included in the diet. The NE of SBH is not different from the NE of WM, and in this experiment, the NE of diets, and ingredients were not influenced by the BW of pigs.

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