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Comparative digestibility of energy and nutrients in fibrous feed ingredients fed to Meishan and Yorkshire pigs

P. E. Urriola[1] and H. H. Stein[2]

Department of Animal Sciences, University of Illinois, Urbana 61801

ABSTRACT: The objective of this experiment was to test the hypothesis that differences in the digestibility of total dietary fiber among breeds of pigs is influenced by the type of fiber fed and also by the age of the pig. Five Meishan pigs (BW: 77.2 ± 15.2 kg; 5 mo old), 5 light Yorkshire pigs (BW: 80.1 ± 11.2 kg; 4 mo old), and 5 heavy Yorkshire pigs (BW: 102.1 ± 3.5 kg, 5 mo old) were surgically prepared with a T-cannula in the distal ileum. A corn-soybean meal diet (control) was formulated with 5 g·kg^{-1} of titanium dioxide as an indigestible marker. Three additional diets were formulated by replacing 30% of the control diet with 30% of distillers dried grains with solubles (DDGS), soybean hulls, or sugar beet pulp, and 1 diet was formulated by replacing 15% of the control diet with 15% pectin. Each group of pigs was allotted to a 5 × 5 Latin square design, and pigs were fed the 5 experimental diets during five 14-d periods. Fecal samples were collected on d 12, and ileal digesta were collected on d 13 and 14 of each period. The apparent ileal digestibility (AID) and apparent total tract digestibility (ATTD) of GE and nutrients in each ingredient were calculated using the substitution method. Hindgut disappearance was calculated as the difference between ATTD and AID. When fed the control diet, Meishan pigs tended ($P < 0.10$) to have a greater AID of GE and CP (78.6 and 80.3%, respectively) than light (77.0 and 78.9%, respectively) and heavy (75.7 and 76.9%, respectively) Yorkshire pigs, and they had a greater ($P < 0.05$) ATTD of DM, GE, and carbohydrates (89.2, 89.5, and 95.5%, respectively) than light (86.6, 86.4, and 92.4%, respectively) and heavy (87.0, 86.6, and 93.0%, respectively) Yorkshire pigs. The ATTD of DM, GE, CP, carbohydrates, and total dietary fiber in DDGS (75.4, 76.3, 81.3, 78.0, and 75.3%, respectively) was greater ($P < 0.01$) in Meishan pigs than in light (55.7, 58.5, 66.7, 49.2, and 39.0%, respectively) and heavy (59.8, 62.9, 70.0, 51.1, and 55.7%, respectively) Yorkshire pigs. There were no differences among the 3 groups of pigs in the ATTD of GE or nutrients in soybean hulls, sugar beet pulp, or pectin. The hindgut disappearance of DM and carbohydrates in DDGS by Meishan pigs (26.8 and 52.9%, respectively) was greater ($P < 0.05$) than in the light (10.0 and 22.8%, respectively) and Heavy Yorkshire pigs (12.2 and 20.0%, respectively), but for the other ingredients, no differences in hindgut disappearance among Meishan, light Yorkshire, and heavy Yorkshire pigs were observed. In conclusion, Meishan pigs have a greater ATTD of DM, GE, and some nutrients in corn-soybean meal diets and in DDGS than Yorkshire pigs.

Key words: digestibility, insoluble dietary fiber, pig, pig breed, soluble dietary fiber, total dietary fiber

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INTRODUCTION

Modern pigs have a relatively poor capacity for digesting dietary fiber, and the apparent total tract digestibility (**ATTD**) of fiber is less than 50% in some feed ingredients when fed to growing pigs (Urriola et al., 2010). However, indigenous breeds of pigs such as Meishan (Kemp et al., 1991), Alentejano (Freire et al., 1998), Mong-Cai (Len et al., 2007), and Mukota (Ndindana et al., 2002) may have a greater capacity for digesting dietary fiber than modern crossbred pigs. Meishan pigs fed a diet based on corn, wheat, and barley had greater ATTD of crude fiber and energy than Dutch Landrace pigs (Kemp et al., 1991). This may be a result of a larger hindgut and a more active microflora in Meishan pigs compared with Dutch Landrace pigs, which may increase the fermentation of fiber and subsequently the absorption of VFA. However, if 15% oats were added to the basal diet, no differences between the 2 groups of pigs were observed (Kemp et al., 1991).

Diets based on corn and 35% dehydrated alfalfa meal were, however, not digested better by 20-kg Meishan pigs than by 20-kg white crossbred pigs (Yen et al.,

[1]Current address: Cargill Animal Nutrition, Elk River, MN 55330.
[2]Corresponding author: hstein@illinois.edu
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2004). It is, therefore, possible that the type of dietary fiber, as well as the breed of the pig, influences ATTD of dietary fiber, but this hypothesis has only been tested with pigs fed sugar beet pulp (von Heimendahl et al., 2010). Sugar beet pulp, however, has a variable concentration of soluble dietary fiber (**SDF**) and insoluble dietary fiber (**IDF**; Sunvold et al., 1995). The dietary fiber in other ingredients, such as distillers dried grains with solubles (**DDGS**), is mostly IDF (Urriola et al., 2010). The objective of this experiment, therefore, was to test the hypothesis that the breed of pigs (Meishan pigs vs. Yorkshire pigs) influences the ATTD of energy, fiber, and other nutrients when pigs are fed diets based on variable amounts of soluble and insoluble dietary fiber.

MATERIALS AND METHODS

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee of the University of Illinois at Urbana-Champaign.

Animals and Housing

Five Meishan pigs (initial BW: 77.2 ± 15.2 kg; 5 mo old) and 10 Yorkshire pigs were surgically prepared with a T-cannula in the distal ileum (Stein et al., 1998). Five of the Yorkshire pigs were the same age as the Meishan pigs (5 mo old) and weighed 102.1 ± 3.5 kg at time of surgery (heavy Yorkshires). The other 5 Yorkshire pigs had an initial BW that was close to that of the Meishan pigs (80.1 ± 11.2 kg), but these pigs were only 4 mo old (light Yorkshires). After surgeries, pigs were allowed to recover for 10 d, and a corn-soybean meal diet was provided on an ad libitum basis during the recovery time. All pigs were housed in individual pens (1.8 × 2.7 m) that had a nipple drinker and a feeder. The floors of the pens were one-half concrete and one-half concrete slats. The room temperature was kept between 20 and 22°C throughout the experiment.

Four feed ingredients with different concentration of IDF and SDF were used (Table 1). The 4 ingredients were DDGS (Lincolnland Agri-Energy, Palestine, IL), soybean hulls (Archer Daniels Midland, Decatur, IL), sugar beet pulp (Siemer Milling Company, Teutopolis, IL), and fruit-derived pectin (TIC Gums, Belcamp, MD). Five diets were formulated (Table 2). The control diet was based on corn and soybean meal and contained 5 g/kg of titanium dioxide (Chicago Sweeteners, Chicago, IL) as an indigestible marker. Three additional diets were formulated by replacing 30% of the control diet with DDGS, soybean hulls, or sugar beet pulp. The last diet was formulated by replacing 15% of the control diet with pectin. Vitamins and minerals were included in all diets to meet or exceed the nutrient requirements of growing pigs (NRC, 1998).

Experimental Design and Sample Collection

Pigs within each group (i.e., Meishan, light Yorkshire, and heavy Yorkshire) were randomly allotted to a 5 × 5 Latin square design with 5 diets and five 14-d periods (Kim and Stein, 2009). Feed was provided to each pig at a daily amount of 2 times the maintenance requirement for energy (i.e., 106 kcal of ME per kg of $BW^{0.75}$; NRC, 1998). The daily feed allotments were divided into 2 equal meals that were provided at 800 and 1700 h.

Fecal samples were collected on d 12 of each period via grab-sampling and stored at −20°C. Ileal digesta were collected on d 13 and 14 of each period following procedures described by Cervantes-Pahm and Stein

Table 1. Analyzed composition of feed ingredients, as-is basis

	Ingredient[1]					
Item	Corn	SBM	DDGS	SBH	SBP	Pectin
GE, kcal/kg	3,881	4,203	5,086	3,771	3,857	3,140
DM, %	87.5	89.7	90.0	85.2	88.4	79.8
CP, %	8.3	47.6	29.3	8.1	10.6	10.6
Acid hydrolyzed ether extract, %	2.2	1.4	16.6	1.6	1.4	0.9
Ash, %	1.2	7.2	4.6	6.0	4.1	2.8
Total dietary fiber, %	8.4	14.3	31.5	57.2	67.0	45.0
Soluble dietary fiber,[2] %	0.4	1.1	0.0	6.2	5.4	41.2
Insoluble dietary fiber, %	8.0	13.2	31.5	51.0	61.6	3.8
NDF, %	10.9	8.8	31.0	42.0	57.4	—
Hemicellulose,[2] %	8.9	2.9	20.6	19.4	16.1	—
ADF, %	2.0	5.9	10.4	22.7	41.3	—
Cellulose,[2] %	1.7	5.4	8.9	21.0	39.9	—
ADL, %	0.3	0.5	1.5	1.7	1.4	—
Water-binding capacity, g/g	1.9	4.4	3.0	6.5	5.5	17.3

[1]SBM = soybean meal; DDGS = distillers dried grains with solubles; SBH = soybean hulls; and SBP = sugar beet pulp.

[2]Soluble dietary fiber was calculated as the difference between total dietary fiber and insoluble dietary fiber; hemicellulose was calculated as the difference between NDF and ADF; and cellulose was calculated as the difference between ADF and ADL.

Table 2. Composition of experimental diets, as-fed basis

	Diet[1]				
Item	Control	DDGS	SBH	SBP	Pectin
Ingredient, %					
Ground corn	76.70	53.69	53.69	53.69	65.20
Soybean meal, 48% CP	18.00	12.60	12.60	12.60	15.30
Distillers dried grains with solubles	—	30.00	—	—	—
Soybean hulls	—	—	30.00	—	—
Sugar beet pulp	—	—	—	30.00	—
Pectin	—	—	—	—	15.00
Soybean oil	2.00	1.40	1.40	1.40	1.70
Ground limestone	1.50	1.05	1.05	1.05	1.28
Monocalcium phosphate	0.90	0.63	0.63	0.63	0.77
Titanium dioxide[2]	0.50	0.35	0.35	0.35	0.43
Vitamin-micromineral premix[3]	0.40	0.28	0.28	0.28	0.34
Total	100.00	100.00	100.00	100.00	100.00
Analyzed composition					
GE, kcal/kg	3,904	4,303	3,874	3,926	3,813
DM, %	87.8	89.5	88.4	89.5	88.6
CP, %	14.9	18.7	13.9	12.5	14.7
Acid hydrolyzed ether extract, %	5.3	8.7	4.1	3.8	4.0
Ash, %	5.4	5.0	5.0	4.9	4.7
Total dietary fiber, %	10.5	16.0	27.1	27.9	18.8
Soluble dietary fiber,[4] %	—	2.6	1.8	3.8	9.7
Insoluble dietary fiber, %	10.5	13.4	25.3	24.1	8.5
Water-binding capacity, g/g	2.2	2.3	3.2	4.0	3.4

[1]DDGS = distillers dried grains with solubles; SBH = soybean hulls; and SBP = sugar beet pulp.

[2]Chicago Sweeteners, Chicago, IL.

[3]The vitamin-micromineral premix provided the following quantities of vitamins and microminerals per kilogram of complete diet: vitamin A, 11,128 IU; vitamin D_3, 2,204 IU; vitamin E, 66 IU; vitamin K, 1.42 mg; thiamine, 0.24 mg; riboflavin, 6.58 mg; pyridoxine, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid, 23.5 mg; niacin, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

[4]Soluble dietary fiber was calculated as the difference between total dietary fiber and insoluble dietary fiber.

(2008). Pig BW was recorded at the beginning of the experiment and at the end of each period to calculate feed allowance for the following period.

Chemical Analyses

At the conclusion of each period, samples were thawed and mixed within animal and diet and a subsample was collected for chemical analysis and stored at –20°C. Ileal and fecal samples were dried to a constant weight in a forced-air oven (60°C) and ground through a 1-mm screen in a Wiley mill (model 4, Thomas Scientific, Swedesboro, NJ). Samples of corn, soybean meal, DDGS, soybean hulls, sugar beet pulp, and pectin, and all diets, ileal samples, and fecal samples were analyzed for DM (method 930.15, AOAC International, 2007), CP (method 990.03; AOAC International, 2007), acid hydrolyzed ether extract (**AEE**; method 996.01, AOAC International, 2007), ash (method 942.15; AOAC International, 2007), and total dietary fiber (**TDF**; method 985.29; AOAC International, 2007). Diets and ingredients were also analyzed for NDF (Holst, 1973), ADF (method 973.18; AOAC International, 2007), ADL [method 973.18 (A–D); AOAC International, 2007], and IDF (method 985.29; AOAC International, 2007). The concentration of GE in ingredients and diets and in ileal and fecal samples was determined using an adiabatic bomb calorimeter (model 6300, Parr Instruments, Moline, IL). Benzoic acid was used as the internal standard. All diets, ileal samples, and fecal samples were also analyzed for titanium concentration following the procedure of Myers et al. (2004).

Water-binding capacity was measured in ingredients and diets by weighing 1 g of sample into a centrifuge tube and mixing with 30 mL of distilled water (Robertson et al., 2000). After stirring, samples were allowed to settle and then centrifuged at 3,000 × g for 20 min at room temperature. The supernatant was removed, and the sample weights were recorded. The water-binding capacity values are expressed as the amount of water retained by the pellet (g/g).

Calculations

The concentration of SDF in diets and ingredients was calculated as the difference between TDF and IDF. Hemicellulose in each sample was calculated as the difference between NDF and ADF, and cellulose was calculated as the difference between ADF and ADL (Van Soest et al., 1991). The concentration of carbohydrates in diets, ileal samples, and fecal samples was calculated according to the following equation:

$$\text{Carbohydrates} = 100 - [\text{CP} + \text{AEE} + \text{ash} + (100 - \text{DM})].$$

Apparent ileal digestibility (**AID**) and ATTD of DM, energy, CP, AEE, ash, TDF, and carbohydrates were calculated in all diets (Eq. 2; Stein et al., 2007). The AID and ATTD of DM, energy, CP, AEE, ash, TDF, and carbohydrates in DDGS, soybean hulls, sugar beet pulp, and pectin were subsequently calculated by the difference procedure (Fan and Sauer, 1995) using the following equation:

$$\text{AD}_{\text{nutrient}} = [(\text{AD}_{\text{assay}} - \text{AD}_{\text{control}}) \times \text{Nutrient}_{\text{control}}]/(1 - \text{Nutrient}_{\text{control}}),$$

where $\text{AD}_{\text{nutrient}}$ is the AID or ATTD of a nutrient in the ingredient (%), AD_{assay} is the AID or ATTD of the nutrient in the assay diet (%), $\text{AD}_{\text{control}}$ is the AID or ATTD of the nutrient in the control diet, and $\text{Nutrient}_{\text{control}}$ is the contribution of the nutrient from the control diet to the assay diet (decimal).

The hindgut disappearance of nutrients, DM, and energy was calculated according to the following equation (Urriola et al., 2010): hindgut $\text{disappearance}_{\text{Nu}} = \text{ATTD}_{\text{Nu}} - \text{AID}_{\text{Nu}}$, where ATTD_{Nu} is the amount of apparent total tract digestible nutrient (g), DM (g), or energy (kcal/kg), and AID_{Nu} is the amount of ileal digestible nutrient (g), DM (g), or energy (kcal/kg).

Statistical Analysis

The UNIVARIATE procedure (SAS Inst. Inc., Cary, NC) was used to confirm normal distribution of the data, equal variances, and to identify outliers. An observation was considered an outlier if the value was more than 3 SD away from the mean, but no outliers were identified. Data were analyzed within each diet by ANOVA using the MIXED procedure of SAS. The group of pigs was the fixed effect, and random effects were the period and the pig nested within group of pigs. Least squares means of the 3 groups of pigs within each diet were calculated using the LSMEAN statement of SAS, the PDIFF option was used to separate means, and multiple comparisons were adjusted by Tukey (Rao, 1998). A similar model was used to calculate and analyze the digestibility values of DM, energy, and nutrients in ingredients. The differences were considered significant if $P < 0.05$ and a trend if $P > 0.05 < 0.10$. The pig was the experimental unit for all analyses.

RESULTS

All pigs were successfully cannulated at the distal ileum and recovered after surgery. The BW at the beginning of period 1 for Meishan, light Yorkshire, and heavy Yorkshire pigs was 82.5 ± 11.6, 90.0 ± 12.4, and 116.7 ± 6.2 kg, respectively. All pigs gained BW during the experiment, and the BW at the beginning of the last period was 92.2 ± 11.1 (Meishans), 116.8 ± 12.0 (light Yorkshires), and 131.0 ± 17.5 kg (heavy Yorkshires).

AID of DM, GE, and Nutrients in Diets

When pigs were fed the control diet, Meishan pigs had a tendency ($P < 0.10$) for a greater AID of GE and CP (78.6 and 80.3%, respectively) than light (77.0 and 78.9%, respectively) and heavy (75.7 and 76.9%, respectively) Yorkshire pigs (Table 3). When pigs were fed the soybean hulls diet, Meishan pigs had a greater ($P < 0.05$) AID of CP (71.0%) than light Yorkshire pigs (66.0%), whereas the AID for CP in heavy Yorkshire pigs (66.7%) was not different from the other 2 groups. When pigs were fed the diet containing 30% sugar beet pulp, heavy Yorkshire pigs had less ($P < 0.05$) AID of CP (64.3%) than Meishan pigs (68.8%), whereas the AID of CP in light Yorkshire pigs (66.9%) was not different from the other 2 groups. When pigs were fed the diet containing pectin, Meishan pigs tended ($P < 0.10$) to have a greater AID of CP (74.9%) than light Yorkshire (71.3%) and heavy Yorkshire pigs (72.0%). There was also a tendency ($P < 0.10$) for a lesser AID of ash in Meishan pigs (−18.2%) than in heavy Yorkshire pigs (−6.6%), whereas the AID of ash in light Yorkshire pigs (−14.5) was not different from that of the other 2 groups.

ATTD of DM, Energy, and Nutrients in Diets

When pigs were fed the control diet, Meishan pigs had a greater ($P \leq 0.05$) ATTD of DM, GE, and carbohydrates (89.2, 89.5, and 95.5%, respectively) than light (86.6, 86.4, and 92.4%, respectively) and heavy (87.0, 86.6, and 93.0%, respectively) Yorkshire pigs (Table 4). When pigs were fed the diet containing 30% DDGS, Meishan pigs also had a greater ($P < 0.01$) ATTD of DM, GE, carbohydrates, and TDF (84.0, 83.5, 90.4, and 66.5%, respectively) than light (78.1, 77.3, 84.5, and 45.8%, respectively) and heavy (79.3, 78.8, 84.9, and 55.3%, respectively) Yorkshire pigs. The ATTD of CP (83.7%) in Meishan pigs was greater ($P < 0.01$) than in light Yorkshire pigs (76.9%), but not different from that of heavy Yorkshire pigs (78.4%). When pigs were fed the sugar beet pulp diet, Meishan pigs tended ($P < 0.10$) to have a greater ATTD of GE (84.7%) than heavy Yorkshire pigs (82.4%), but no differences were observed for the ATTD of DM and nutrients. There were also no differences among the 3 groups of pigs in the ATTD of DM, GE, or nutrients in the diets containing soybean hulls or pectin.

Hindgut Disappearance of DM, Energy, and Nutrients in Diets

When fed the DDGS diet, Meishan pigs had a greater ($P < 0.01$) hindgut disappearance of DM and carbohydrates (15.1 and 20.2%, respectively) than light (10.1

Table 3. Apparent ileal digestibility (%) of DM, energy, and nutrients in experimental diets[1,2]

Item	DM	GE	CP	AEE	Ash	CHO	TDF
Control diet							
Meishan	79.0	78.6	80.3	67.4	34.1	83.6	20.4
Light Yorkshire	76.7	77.0	78.9	68.2	34.0	80.7	25.8
Heavy Yorkshire	77.1	75.7	76.9	68.6	39.4	81.3	23.8
SEM	1.0	0.9	1.0	2.6	2.5	1.3	6.6
P-value	0.28	0.09	0.10	0.95	0.25	0.30	0.85
Distillers dried grains with solubles diet							
Meishan	68.9	70.7	75.9	72.9	27.7	70.2	28.0
Light Yorkshire	68.0	69.0	73.2	64.5	31.3	70.4	21.6
Heavy Yorkshire	68.6	70.0	71.8	70.0	27.8	71.4	33.8
SEM	0.9	1.0	1.5	2.9	3.5	1.3	5.3
P-value	0.76	0.50	0.21	0.17	0.70	0.78	0.31
Soybean hull diet							
Meishan	58.3	59.9	71.0[a]	59.8	10.5	59.4	44.6
Light Yorkshire	58.3	59.2	66.0[b]	55.5	11.8	60.5	49.3
Heavy Yorkshire	58.2	59.5	66.7[ab]	55.5	18.0	59.7	50.6
SEM	1.6	1.5	1.3	3.1	3.6	1.6	5.6
P-value	0.99	0.94	0.04	0.56	0.32	0.88	0.73
Sugar beet pulp diet							
Meishan	61.7	64.4	68.8[a]	67.6	−54.8	68.5	37.4
Light Yorkshire	59.7	62.9	66.9[ab]	62.6	−47.8	65.9	46.1
Heavy Yorkshire	60.4	62.1	64.3[b]	61.7	−38.1	66.9	44.1
SEM	1.7	1.6	1.2	3.6	9.1	1.8	5.4
P-value	0.68	0.60	0.02	0.47	0.45	0.62	0.52
Pectin diet							
Meishan	67.7	69.2	74.9	66.1	−21.8	73.2	29.8
Light Yorkshire	65.7	67.8	71.3	53.0	−14.5	71.5	26.0
Heavy Yorkshire	66.8	68.5	72.0	57.0	−6.6	72.0	28.2
SEM	0.85	0.9	1.5	4.8	3.2	0.9	4.8
P-value	0.11	0.28	0.06	0.16	0.06	0.31	0.71

[a,b]Means within a column and diet lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means of 5 observations.

[2]AEE = acid hydrolyzed ether extract; CHO = carbohydrates; and TDF = total dietary fiber.

and 14.0%, respectively) and heavy (10.7 and 13.5%, respectively) Yorkshire pigs (Table 5). There was also a tendency ($P < 0.10$) for a greater hindgut disappearance of GE for Meishan pigs (12.9%) than for light (8.3%) and heavy (8.8%) Yorkshire pigs. There were no differences among the 3 groups of pigs in hindgut disappearance of DM, GE, or nutrients when pigs were fed the control, soybean hulls, sugar beet pulp, or pectin diets. Values for the hindgut disappearance of AEE were negative for all diets.

AID of DM, GE, and Nutrients in Feed Ingredients

The AID of DM, GE, and nutrients in DDGS and soybean hulls were not different among the 3 groups of pigs (Table 6). The AID of CP in sugar beet pulp was greater ($P < 0.05$) in Meishan (37.9%) and light Yorkshire pigs (33.1%) than in heavy (22.7%) Yorkshire pigs, but the AID of DM, GE, or other nutrients was not different among the 3 groups of pigs. The AID of ash in pectin by Meishan pigs (−577.4%) tended ($P < 0.10$) to be less than in heavy Yorkshire pigs (−421.4%), whereas the AID of ash in light Yorkshire pigs (−506.9%) was not different from the other 2 groups.

ATTD of DM, Energy, and Nutrients in Ingredients

The ATTD of DM, GE, CP, and carbohydrates in DDGS (Table 7) by Meishan pigs (75.4, 76.3, 81.3, and 78.0%, respectively) were greater ($P < 0.01$) than in light Yorkshire pigs (55.7, 58.5, 66.7, and 49.2%, respectively) and heavy Yorkshire pigs (59.8, 62.9, 70.0, and 51.1%, respectively). The ATTD of TDF in DDGS was greater ($P < 0.01$) in Meishan pigs (75.3%) than in heavy (55.7%) and light Yorkshire pigs (39.0%), and the ATTD of TDF was also greater ($P < 0.05$) in heavy than in light Yorkshire pigs. There were no differences in the ATTD of AEE and ash in DDGS among the 3 groups of pigs. There were also no differences in the ATTD of DM, energy, and nutrients in soybean hulls, sugar beet pulp, and pectin among the 3 groups of pigs.

Hindgut Disappearance of DM, Energy, and Nutrients in Ingredients

The disappearance of DM and carbohydrates in DDGS by Meishan pigs (26.8 and 52.9%, respectively) were greater ($P < 0.01$) than in light (10.0 and 22.8%, respectively) and heavy (12.2 and 20.0%, respectively) Yorkshire pigs (Table 8). Meishan pigs also tended (*P*

Table 4. Apparent total tract digestibility (%) of DM, energy, and nutrients in experimental diets[1,2]

Item	DM	GE	CP	AEE	Ash	CHO	TDF
Control diet							
Meishan	89.3[a]	89.5[a]	87.4	64.9	47.2	95.5[a]	58.0
Light Yorkshire	86.6[b]	86.4[b]	85.2	63.1	47.6	92.4[b]	54.4
Heavy Yorkshire	87.0[ab]	86.6[b]	85.0	62.1	50.9	93.0[b]	52.0
SEM	0.6	0.8	1.1	2.0	1.9	0.4	1.8
P-value	0.02	0.03	0.24	0.62	0.36	<0.01	0.11
Distillers dried grains with solubles diet							
Meishan	84.0[a]	83.5[a]	83.7[a]	63.8	47.2	90.4[a]	66.5[a]
Light Yorkshire	78.1[b]	77.3[b]	76.9[b]	57.1	45.6	84.5[b]	45.8[c]
Heavy Yorkshire	79.3[b]	78.8[b]	78.4[ab]	62.8	48.3	84.9[b]	55.3[b]
SEM	1.0	1.0	1.1	2.4	3.2	1.0	2.2
P-value	<0.01	<0.01	<0.01	0.15	0.24	<0.01	<0.01
Soybean hull diet							
Meishan	85.4	84.1	76.2	45.7	52.0	92.0	84.1
Light Yorkshire	81.3	79.5	70.7	43.3	49.8	87.9	78.6
Heavy Yorkshire	82.2	80.1	71.3	42.5	53.2	88.7	77.7
SEM	1.7	1.8	2.0	4.5	1.3	2.0	2.6
P-value	0.25	0.19	0.13	0.88	0.23	0.36	0.20
Sugar beet pulp diet							
Meishan	85.1	84.7	76.7	44.0	31.7	92.4	80.9
Light Yorkshire	84.0	83.3	73.5	45.0	38.8	91.0	78.1
Heavy Yorkshire	83.8	82.4	71.7	40.2	39.6	91.1	76.8
SEM	0.76	0.9	2.0	1.6	3.6	0.5	1.9
P-value	0.40	0.08	0.25	0.12	0.27	0.12	0.66
Pectin diet							
Meishan	87.6	86.7	84.0	52.4	41.2	94.3	71.6
Light Yorkshire	85.7	84.3	81.0	52.8	41.8	92.3	72.9
Heavy Yorkshire	86.5	85.4	81.0	53.9	44.4	93.1	73.5
SEM	1.0	1.1	1.7	4.7	4.8	0.7	3.3
P-value	0.40	0.38	0.39	0.97	0.88	0.14	0.92

[a–c]Means within a column and diet lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means of 5 observations.

[2]AEE = acid hydrolyzed ether extract; CHO = carbohydrates; and TDF = total dietary fiber.

< 0.10) to have a greater hindgut fermentation of GE (17.4%) than light (4.50%) and heavy (7.1%) Yorkshire pigs. However, for soybean hulls, sugar beet pulp, and pectin, no differences in hindgut disappearance of DM, GE, and nutrients among Meishan, light Yorkshire, and heavy Yorkshire pigs were observed.

DISCUSSION

Meishan pigs gained much less BW during the experiment than the light and the heavy Yorkshire pigs, which may be a result of Meishan pigs gaining more fat relative to lean compared with Yorkshire pigs. Because fat retention requires more energy than lean retention, the restricted amount of energy that was provided to pigs each day resulted in less BW gain for the Meishan pigs when measured in kilograms compared with the Yorkshire pigs.

The ATTD of TDF in DDGS is only 46% (Urriola et al., 2010), which is the reason for the relatively low ATTD of DM and GE in corn-based coproducts (Stein and Shurson, 2009). In contrast, the ATTD of TDF in sugar beet pulp and pectin are 71.8 and 90%, respectively (Graham et al., 1986; Drochner et al., 2004), and the ATTD of hemicellulose and cellulose in soybean hulls is 58.9 and 82.1%, respectively (Kornegay, 1981). The TDF in DDGS is mainly IDF, whereas soybean hulls, sugar beet pulp, and pectin contain greater concentrations of SDF, which is likely the reason for the reduced ATTD of TDF in DDGS compared with soybean hulls, sugar beet pulp, and pectin because the ATTD of IDF is much less than the ATTD of SDF (Urriola et al., 2010).

The ATTD of crude fiber in 28-kg Meishan pigs (47.8%) is greater than in Dutch Landrace pigs of similar BW (36.4%; Kemp et al., 1991), but 20-kg Meishan pigs had ATTD of crude fiber that was not different from the ATTD of crude fiber by 20-kg white crossbred pigs (Yen et al., 2004). Other indigenous breeds of pigs such as Mong Cai (Vietman) and Mukota (Zimbabwe) also have greater ATTD of NDF, ADF, and crude fiber than modern crossbred pigs (Ndindana et al., 2002; Len et al., 2007, 2009), but the ATTD of dietary fiber in Kune-Kune and Haellisches Schwein or Bunte Bentheimer pigs is not different from that of modern crossbred pigs (Morel et al., 2006; von Heimendahl et al., 2010). The reason for these different results among experiments may be that the ATTD of fiber is influenced not only by the breed of pigs, but also by the

Table 5. Hindgut disappearance (%) of DM, energy, and nutrients in experimental diets[1,2]

Item	DM	GE	CP	AEE	Ash	CHO	TDF
Control diet							
Meishan	10.3	10.9	7.1	−2.6	13.1	12.0	37.5
Light Yorkshire	9.9	9.5	6.3	−6.4	13.6	11.8	28.7
Heavy Yorkshire	10.0	10.9	8.0	−2.5	11.5	11.7	28.2
SEM	1.2	1.2	1.6	3.0	3.0	1.3	6.5
P-value	0.97	0.66	0.75	0.66	0.87	0.99	0.54
Distillers dried grains with solubles diet							
Meishan	15.1[a]	12.9	7.9	−9.1	19.5	20.2[a]	38.5
Light Yorkshire	10.1[b]	8.3	3.7	−7.4	14.2	14.0[b]	24.1
Heavy Yorkshire	10.7[b]	8.8	6.7	−7.2	20.5	13.5[b]	21.5
SEM	0.9	1.3	2.0	2.4	2.8	1.2	6.4
P-value	<0.01	0.06	0.35	0.78	0.27	<0.01	0.17
Soybean hull diet							
Meishan	27.1	24.2	5.2	−14.1	41.4	32.5	39.5
Light Yorkshire	19.8	20.3	4.7	−12.2	38.0	27.4	29.2
Heavy Yorkshire	21.1	20.7	4.6	−13.1	35.2	29.0	27.0
SEM	2.2	2.4	2.3	5.2	3.0	2.3	6.4
P-value	0.41	0.48	0.98	0.97	0.37	0.31	0.37
Sugar beet pulp diet							
Meishan	23.4	20.4	7.9	−23.6	86.5	23.7	43.5
Light Yorkshire	24.3	20.4	6.6	−17.7	86.6	25.0	32.0
Heavy Yorkshire	23.3	20.2	7.4	−21.5	77.7	24.2	32.8
SEM	2.0	1.9	2.3	4.5	9.6	2.0	6.1
P-value	0.92	1.00	0.84	0.65	0.75	0.91	0.46
Pectin diet							
Meishan	19.9	17.4	9.1	−13.7	63.0	21.1	41.8
Light Yorkshire	20.0	16.5	9.7	−0.3	56.3	20.8	46.9
Heavy Yorkshire	19.7	16.9	8.9	−3.0	51.0	21.0	45.4
SEM	1.4	1.3	2.5	6.5	6.1	1.0	5.4
P-value	0.98	0.90	0.97	0.33	0.45	0.97	0.79

[a,b]Means within a column and diet lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means of 5 observations.

[2]AEE = acid hydrolyzed ether extract; CHO = carbohydrates; and TDF = total dietary fiber.

Table 6. Apparent ileal digestibility (%) of DM, energy, and nutrients in ingredients[1,2]

Item	DM	GE	CP	AEE	Ash	CHO	TDF
Distillers dried grains with solubles							
Meishan	48.6	58.9	72.6	75.6	2.0	25.1	31.4
Light Yorkshire	45.7	54.0	66.9	62.4	17.2	26.4	20.4
Heavy Yorkshire	47.6	55.8	64.0	70.6	2.3	31.1	41.7
SEM	2.8	2.9	3.2	4.6	14.4	6.2	9.3
P-value	0.76	0.50	0.21	0.17	0.70	0.78	0.31
Soybean hulls							
Meishan	13.4	20.5	36.0	13.5	−35.1	13.5	63.3
Light Yorkshire	13.3	18.1	8.5	−14.4	−31.5	16.9	72.2
Heavy Yorkshire	12.8	19.0	12.3	−14.3	−14.1	14.3	74.7
SEM	5.2	5.0	7.0	20.5	10.0	4.9	10.6
P-value	0.99	0.94	0.04	0.56	0.32	0.88	0.73
Sugar beet pulp							
Meishan	24.7	34.5	37.9[a]	64.6	−321.6	40.3	43.1
Light Yorkshire	17.9	29.7	33.1[a]	27.5	−293.9	31.8	55.2
Heavy Yorkshire	20.3	27.0	22.7[b]	20.7	−255.5	34.3	52.4
SEM	5.5	5.2	3.7	26.4	35.8	5.9	7.6
P-value	0.68	0.60	0.04	0.47	0.45	0.59	0.52
Pectin							
Meishan	11.7	20.0	46.9	16.0	−577.4	30.3	35.4
Light Yorkshire	−1.9	9.3	16.7	−327.4	−506.9	20.3	28.3
Heavy Yorkshire	5.8	14.0	22.7	−225.8	−421.4	23.5	32.5
SEM	5.7	5.9	11.8	126.6	40.1	5.5	9.0
P-value	0.28	0.45	0.20	0.17	0.06	0.44	0.71

[a,b]Means within a column and ingredient lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means of 5 observations.

[2]AEE = acid hydrolyzed ether extract; CHO = carbohydrates; and TDF = total dietary fiber.

Table 7. Apparent total tract digestibility (%) of DM, energy, and nutrients in ingredients[1,2]

Item	DM	GE	CP	AEE	Ash	CHO	TDF
Distillers dried grains with solubles							
Meishan	75.4[a]	76.3[a]	81.3[a]	64.0	42.8	78.0[a]	75.3[a]
Light Yorkshire	55.7[b]	58.5[b]	66.7[b]	53.6	36.2	49.2[b]	39.0[c]
Heavy Yorkshire	59.8[b]	62.9[b]	70.0[b]	62.5	47.2	51.1[b]	55.7[b]
SEM	3.3	2.9	2.4	3.8	8.3	6.7	3.8
P-value	<0.01	<0.01	<0.01	0.15	0.65	0.02	<0.01
Soybean hulls							
Meishan	80.2	76.4	32.7	−52.9	58.1	88.5	109.9
Light Yorkshire	66.6	61.1	2.1	−68.3	52.1	76.3	99.5
Heavy Yorkshire	69.3	63.2	5.4	−73.9	61.4	78.6	97.8
SEM	5.8	5.9	10.8	29.7	3.7	6.1	4.8
P-value	0.25	0.19	0.13	0.88	0.23	0.36	0.20
Sugar beet pulp							
Meishan	79.2	78.2	50.3	−80.7	−17.9	89.7	91.4
Light Yorkshire	75.5	73.5	38.0	−73.7	10.1	85.2	87.5
Heavy Yorkshire	74.7	70.3	31.0	−108.0	13.2	85.8	85.7
SEM	2.5	2.8	7.8	11.8	14.1	1.5	1.7
P-value	0.43	0.18	0.25	0.12	0.27	0.12	0.10
Pectin							
Meishan	87.5	81.1	70.0	−225.4	−30.5	97.6	86.1
Light Yorkshire	74.7	64.2	45.3	−215.1	−24.9	85.6	88.5
Heavy Yorkshire	80.0	72.2	45.2	−185.7	3.9	90.3	89.6
SEM	6.5	8.3	14.1	124.3	51.6	4.0	6.1
P-value	0.41	0.38	0.39	0.97	0.88	0.14	0.92

[a–c]Means within a column and ingredient lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means of 5 observations.

[2]AEE = acid hydrolyzed ether extract; CHO = carbohydrates; and TDF = total dietary fiber.

type of fiber and the age of the pigs. It is also possible that differences among experiments may be caused by allowing pigs different periods of time to adapt to fiber-rich ingredients. Fermentation of fiber may increase over time because the microflora of the pigs may adapt to the diet.

Table 8. Hindgut disappearance (%) of DM, energy, and nutrients in experimental feed ingredients[1,2]

Item	DM	GE	CP	AEE	Ash	CHO	TDF
Distillers dried grains with solubles							
Meishan	26.8[a]	17.4	8.8	−11.6	40.8	52.9[a]	43.8
Light Yorkshire	10.0[b]	4.5	−0.2	−8.9	19.0	22.8[b]	18.6
Heavy Yorkshire	12.2[b]	7.1	5.9	−8.1	44.9	20.0[b]	14.0
SEM	2.9	3.6	4.3	3.7	11.4	5.7	11.4
P-value	<0.01	0.06	0.35	0.78	0.27	<0.01	0.17
Soybean hulls							
Meishan	66.8	55.9	−3.3	−66.4	93.2	75.1	46.6
Light Yorkshire	53.3	43.0	−6.4	−54.0	83.7	59.4	27.3
Heavy Yorkshire	56.5	44.2	−6.9	−59.6	75.5	64.3	23.1
SEM	7.2	8.0	12.4	34.2	8.5	7.1	12.0
P-value	0.41	0.48	0.98	0.97	0.37	0.31	0.37
Sugar beet pulp							
Meishan	54.5	43.7	12.4	−145.3	303.7	49.3	48.3
Light Yorkshire	57.6	43.8	5.0	−101.2	304.1	53.4	32.3
Heavy Yorkshire	54.3	43.3	8.2	−129.5	268.7	51.5	33.3
SEM	6.5	6.3	8.7	33.3	37.8	6.4	7.8
P-value	0.92	0.99	0.84	0.65	0.75	0.90	0.30
Pectin							
Meishan	75.8	61.1	23.1	−241.3	547.0	67.3	50.6
Light Yorkshire	76.6	54.9	28.6	112.3	482.0	65.3	60.2
Heavy Yorkshire	74.5	58.3	22.4	40.1	425.3	67.2	57.4
SEM	9.2	9.5	20.7	169.6	66.0	6.22	8.5
P-value	0.98	0.90	0.97	0.33	0.45	0.97	0.55

[a,b]Means within a column and ingredient lacking a common superscript letter are different ($P < 0.05$).

[1]Data are least squares means of 5 observations.

[2]AEE = acid hydrolyzed ether extract; CHO = carbohydrates; and TDF = total dietary fiber.

In the present experiment, Meishan and Yorkshire pigs had similar ATTD of GE and nutrients when fed diets based on soybean hulls, sugar beet pulp, and pectin. This observation is consistent with the fact that there are no differences in ATTD of NDF in sugar beet pulp among Schwaebisch Haellisches Schwein, Bunte Bentheimer, and modern crossbred pigs (von Heimendahl et al., 2010). However, Meishan pigs had a greater ATTD of TDF than Yorkshire pigs when pigs were fed diets with a greater proportion of IDF (control and DDGS diets). This observation indicates that Meishan pigs have a greater capacity to digest IDF than Yorkshire pigs, whereas there is no difference between the 2 breeds in the capacity to digest SDF. This is not a surprise because the ATTD of SDF in modern breeds of pigs is close to 90% (Serena et al., 2008; Urriola et al., 2010) as was also observed for the ATTD of TDF in pectin in this experiment.

The ATTD of TDF and energy is influenced by the age of the pig (Le Goff and Noblet, 2001). To separate the effects of BW and age, we attempted to compare the ATTD of energy and nutrients in Meishan pigs to Yorkshire pigs that were either of the same age or had a starting BW that was similar to the Meishan pigs. The fact that Meishan pigs and heavy Yorkshire pigs had a greater ATTD of TDF than light Yorkshire pigs when fed DDGS, but not when fed soybean hulls, sugar beet pulp, or pectin, indicates that age-related differences in the ATTD of fiber are caused by differences in the ATTD of IDF, whereas age does not influence the ATTD of SDF. This observation is in agreement with Le Goff and Noblet (2001) and with Jørgensen et al. (2007) who reported that the ATTD of GE and dietary fiber were not different among modern crossbred growing pigs, finishing pigs, and sows when fed diets based on sugar beet pulp, which contains large proportions of SDF. However, if pigs were fed diets based on wheat bran or corn bran, which mainly contain IDF, sows had greater ATTD of GE and fiber than growing and finishing pigs and finishing pigs had a grater ATTD of GE and fiber than growing pigs.

Greater ATTD of IDF by older pigs than by younger pigs may be explained by differences in feed intake, differences in the size of the intestines, and differences in the capacity of microbes to ferment IDF (Varel et al., 1988; Dierick et al., 1989; Varel and Yen, 1997). In the current experiment, feed intake was equalized among the 3 groups of pigs; thus, differences in feed intake did not contribute to the observed differences among pigs. However, Meishan pigs have larger intestines relative to their BW than white crossbred pigs (Yen et al., 2004), which may have contributed to the increased ATTD of IDF and GE. The greater ATTD of IDF in Meishan pigs than Yorkshire pigs may also have been due to a greater capacity of the microflora in Meishan pigs to digest fiber. However, the concentrations of total viable bacteria and cellulitic bacteria in the feces of Meishan pigs at 13, 17, and 19 wk of age were not different from those of white crossbred pigs (Yen et al., 2004), and the capacity to ferment fiber is not different between sows and growing pigs (Le Goff et al., 2003). Meishan pigs have greater intestinal concentrations of Bacteroides and Firmicutes than Yorkshire pigs (Guo et al., 2008), and these differences contribute to an increase in digestibility of dietary energy in mice (Turnbaugh et al., 2006).

Hindgut disappearance was calculated as the difference between ATTD and AID, but dietary fiber is defined as the carbohydrates that are resistant to digestion by mammalian enzymes (AACC, 2001). Therefore, any disappearance of fiber in the small intestine may be considered a result of fermentation in the small intestine, but results of this experiment indicate that there were no differences among breeds in the AID of dietary fiber. We are not aware of any previous data that compared the AID of TDF among different breeds of pigs.

The negative hindgut disappearance of AEE for all diets and for DDGS and soybean hulls is most likely a consequence of synthesis of fatty acids in the hindgut because the presence of carbohydrates in the hindgut allows microbes to synthesize fatty acids. No synthesis of fat takes place in the hindgut of pigs fed low-fiber diets, but if pigs are fed high-fiber diets, fat is synthesized in the hindgut, which results in decreased values for the ATTD compared with the AID of AEE (Kil et al., 2010). This, in turn, results in negative calculated values for hindgut disappearance of AEE (Kil et al., 2010).

The negative values for the AID of ash in soybean hulls, sugar beet pulp, and pectin, but not in DDGS, indicate that ingredients that contain substantial quantities of SDF may draw minerals into the stomach or small intestine or both. This observation is in agreement with data showing that AID of ash in sugar beet pulp (−116%) is much less than in wheat bran (−3.9%; Graham et al., 1986).

The AID of TDF in DDGS that was determined in this experiment agrees with the value of 24% that has previously been reported (Urriola et al., 2010). The AID for TDF in all diets are also within the range for AID of TDF (−10 to 62%) that has been reported for diets containing a large variety of feed ingredients (Bach Knudsen and Jørgensen, 2001).

Because the AID as well as the hindgut disappearance of TDF is a result of fermentation, values for the ATTD of TDF represent the total fermentation of fiber. The energy contribution from fermentation in the small intestine and in the hindgut is a result of absorption of VFA, and therefore, the total energy contribution from fermentation of fiber can be calculated from the ATTD of fiber. However, the energy value of dietary fiber depends not only on the VFA produced after fermentation, but also on the effects of fiber on the digestibility of other nutrients (Elia and Cummings, 2007; Bindelle et al., 2009). Endogenous losses of AEE may also increase with increasing dietary fiber (Kil et al., 2010), and the apparent digestibility of AEE, therefore, may decrease with addition of fiber to the diet (Bach Knudsen and Hansen, 1991; Dégen et al., 2009). The negative values for AID and ATTD of AEE in soybean hulls and pectin indicate that the fiber in these ingredients may have promoted a net secretion of AEE into the gut in addition to a net synthesis of AEE in the hindgut. The reason no negative AID and ATTD values for AEE were observed for DDGS is most likely that the concentration of AEE in DDGS is greater than in the other ingredients and the influence of endogenous losses of a nutrient are much greater in diets with reduced concentrations of that nutrient than in diets with greater concentrations (Stein et al., 2007; Kil et al., 2010).

In conclusion, Meishan pigs had a greater ATTD of TDF than Yorkshire pigs when fed diets in which most of the fiber was IDF such as the control and the DDGS diets. There were, however, no differences among the 3 groups of pigs when pigs were fed diets containing soybean hulls, sugar beet pulp, or pectin, which contain more SDF. This indicates that Meishan pigs are more efficient in fermenting IDF than Yorkshire pigs, whereas there are no differences between Meishan and Yorkshire pigs in their ability to ferment SDF. It is possible that this difference is a result of differences in the microbial population, but further research is needed to determine the influence of breed on intestinal microbial populations.

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