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Comparative digestibility of energy and nutrients in diets fed to sows and growing pigs

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The objective of this research was to compare values for digestible energy (DE) and metabolisable energy (ME) and apparent total tract digestibility (ATTD) of nutrients in 11 diets fed to both growing pigs and gestating sows. Three diets were based on corn, wheat or sorghum and eight diets were based on a combination of corn and soybean meal, canola meal, conventional distillers' dried grains with solubles, low-fat distillers' dried grains with solubles, corn germ meal, corn bran, wheat middlings or soybean hulls. A total of 88 gestating sows (252 ± 24.2 kg BW; parity two to six) and 88 growing barrows (40 ± 4.7 kg BW) were used and randomly allotted to the 11 diets with eight replicate sows or pigs per diet. Faecal and urine samples were collected for 4 d following a 19 d adaptation period. The DE, ME and ATTD of gross energy (GE), acid detergent fibre (ADF), neutral detergent fibre (NDF) and crude protein (CP) in the 11 diets were calculated. Gestating sows had greater ($p < 0.05$) ATTD of GE and CP and DE values for all diets compared with growing pigs. Gestating sows also had greater ($p < 0.05$) ME values than growing pigs for the three grain diets and the diets containing wheat middlings and soybean hulls. No differences were observed in ATTD of ADF and NDF between gestating sows and growing pigs for any of the diets, except that gestating sows had greater ($p < 0.05$) ATTD of NDF than growing pigs when they were fed the four protein diets. The ATTD of GE and CP and DE values in gestating sows may be predicted by using equations generated from the values of ATTD of GE and CP and DE values obtained in growing pigs. Results of this research indicate that ATTD values of CP and GE obtained in gestating sows are greater than the values obtained in growing pigs, but values for ATTD of ADF obtained in growing pigs are not different from values in gestating sows.

Keywords: digestibility; energy; gestation; growth period; nutrients; pigs; prediction

1. Introduction

Sows have greater apparent total tract digestibility (ATTD) of several nutrients compared with growing pigs (Fernández et al. 1986). Values for digestible energy (DE) and metabolisable energy (ME) in diets and feed ingredients are dependent on the physiological stage/body weight (BW) of the animal and/or feeding level, but increased ATTD also results in greater ME of diets (Shi and Noblet 1993a, 1994). Sows may have a greater ability to ferment fibre because they have a larger digestive tract than growing pigs (Fernández et al. 1986; Shi and Noblet 1993a; Le Goff and Noblet 2001) and the greater digestibility of energy and OM in sows may be a result of the greater ability of sows to ferment fibre compared with growing pigs (Shi and Noblet 1993b).

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Although results of several European experiments have indicated that DE, ME and ATTD of gross energy (GE) and nutrients are greater in gestating sows fed close to the maintenance requirement for energy than in growing pigs allowed *ad libitum* access to feed, to our knowledge, no data from North America for the comparative ATTD of energy have been reported. As use of high-fibre ingredients increases in the United States, such values are needed to accurately formulate diets for growing pigs and sows. Therefore, the objective of this research was to test the hypothesis that values for the ATTD of energy and nutrients and the DE and ME content of diets are greater in gestating sows than in growing pigs.

2. Materials and methods

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocol, 11099, for this experiment.

Eleven feed ingredients were used (Tables 1–3). Three of the ingredients were cereal grains (corn, sorghum and wheat), four ingredients were commonly used protein sources [soybean meal (SBM), canola meal, conventional distillers' dried grains with solubles (DDGS-CV) and low-fat DDGS (LF-DDGS)] and the remaining four ingredients were commonly used high-fibre ingredients [corn germ meal (CGM), corn bran, wheat middlings (WM) and soybean hulls (SBH)].

2.1. Animal and diets

A total of 88 gestating sows (251.8 ± 24.2 kg BW), parities two to six and 88 growing barrows (40.1 ± 4.69 kg BW) were used in the experiment. Sows were Fertilis-25 females and barrows were the offspring of G-performer males mated to Fertilis-25 females (Genetiporc, Alexandria, Minnesota, United States). Pigs and sows were placed in metabolism crates that are equipped with a feeder and a nipple drinker, slatted floors, a screen floor and urine trays. The crates allow for the total, but separate, collection of urine and faeces from each individual animal. Metabolism crates for pigs are 0.9 × 1.8 m, whereas metabolism crates for sows are 0.9 × 2.1 m. The average room temperature and humidity where pigs were housed was 24.7 ± 3.5°C and 61.1 ± 15.8%, respectively. The average room temperature and humidity where sows were housed was 20.9 ± 2.2°C and 40.6 ± 22.0%, respectively. Pigs and sows were provided 24-hour light.

Eleven diets were formulated (Tables 4 and 5). Three diets were based on corn, sorghum or wheat and eight diets were based on a combination of corn and each of the remaining eight ingredients. Diets containing SBM, canola meal, LF-DDGS or DDGS-CV were formulated to contain the same amount of crude protein (CP). Vitamins and minerals were included in all diets to meet estimates for current requirements (NRC 2012). The same diets were fed to sows and to growing pigs. A randomised complete block design was used within each group of animals, and the 88 animals within each group were randomly allotted to the 11 diets with eight blocks of 11 sows for a total of eight replicate sows per diet and four blocks of 22 growing pigs, which resulted in a total of eight replicate growing pigs per diet.

Feed was provided daily in an amount of 1.5 and 3.4 times the estimated energy requirement for maintenance in gestating sows and growing pigs, respectively. Daily feed rations were divided into two equal meals that were provided at 07:00 and 16:00 h, respectively. Pigs and sows were allowed *ad libitum* access to water throughout the experiment. Diets were fed to the animals for a total of 24 d. The initial 14 d were considered an adaptation period to the diet, and during this period, pigs and sows were adapted to their respective diet in

Table 1. Analysed nutrient composition of corn, wheat, sorghum, soybean meal (SBM), canola meal, conventional distillers' dried grains with solubles (DDGS-CV), low fat distillers' dried grains with solubles (LF-DDGS), corn germ meal (CGM), corn bran, wheat middlings and soybean hulls [as-fed basis].

	Ingredients										
	Corn	Wheat	Sorghum	SBM	Canola meal	DDGS-CV	LF-DDGS	CGM	Corn bran	Wheat middlings	Soybean hulls
Gross energy [MJ/kg]	16.69	16.14	16.11	17.87	17.82	20.01	18.32	17.55	17.91	17.19	15.23
Dry matter [g/kg]	917.3	904.9	881.6	904.9	891.2	887.7	884.4	888.1	910.9	897.2	870.3
Crude protein [g/kg]	91.7	110.0	100.1	503.3	358.3	293.4	332.8	245.0	102.5	161.3	99.7
Ether extract* [g/kg]	29.7	18.6	27.2	43.0	24.2	122.0	79.9	37.3	40.9	51.8	11.4
Ash [g/kg]	11.7	16.1	12.0	61.7	78.4	46.4	61.7	30.5	8.90	58.1	43.6
Organic matter [g/kg]	905.6	888.8	869.6	843.2	812.8	841.3	822.7	857.6	902.0	839.1	826.7
Ca [g/kg]	0.10	0.40	0.10	3.30	10.1	0.30	0.40	0.20	0.10	1.00	5.40
P [g/kg]	2.30	3.20	2.60	6.80	10.7	8.40	9.70	7.50	1.20	12.0	1.00
Cl [g/kg]	<1.00	<1.00	<1.00	<1.00	2.00	2.00	2.00	2.00	2.00	<1.00	<1.00
Mg [g/kg]	1.00	1.20	1.30	3.10	6.50	3.50	4.00	2.60	0.60	5.00	2.00
K [g/kg]	3.10	3.80	3.30	24.0	12.7	12.1	13.0	4.60	2.60	13.3	13.6
S [g/kg]	1.10	1.40	0.90	4.50	9.80	8.00	9.50	3.40	1.80	2.20	1.10
Na [mg/kg]	8.00	<0.20	<0.20	55.0	219.0	1025	2332	166.00	38.00	34.00	5.00
Cu [mg/kg]	6.00	10.00	6.00	34.00	21.00	14.00	14.00	17.00	6.00	29.00	11.00
Fe [mg/kg]	62.00	72.00	56.00	154.00	268.00	163.00	145.00	219.00	166.00	225.00	459.00
Zn [mg/kg]	36.00	26.00	18.00	45.00	65.00	79.00	75.00	93.00	21.00	105.00	31.00
Mn [mg/kg]	6.00	52.00	16.00	32.00	87.00	16.00	17.00	14.00	4.00	147.00	12.00
Se [mg/kg]	<4.00	<4.00	<4.00	<4.00	<4.00	<4.00	<4.00	<4.00	<4.00	<4.00	<4.00

Note: *Acid hydrolysed.

Table 2. Analysed carbohydrate concentration and physical characteristics of corn, wheat, sorghum, soybean meal (SBM), canola meal, conventional distillers' dried grains with solubles (DDGS-CV), low fat distillers' dried grains with solubles (LF-DDGS), corn germ meal (CGM), corn bran, wheat middlings and soybean hulls [as-fed basis].

	Ingredients										
	Corn	Wheat	Sorghum	SBM	Canola meal	DDGS-CV	LF-DDGS	CGM	Corn bran	Wheat middlings	Soybean hulls
Carbohydrates [g/kg]											
Glucose	4.40	3.90	3.60	13.4	6.80	2.70	3.70	1.90	4.60	17.4	3.10
Fructose	4.70	3.30	1.80	7.90	6.50	0.80	1.00	6.80	5.40	13.1	12.5
Sucrose	10.2	4.70	0.40	75.1	54.7	0.30	0.00	0.90	0.00	6.90	3.60
Maltose	1.50	1.10	0.60	4.50	0.00	6.70	3.30	0.30	0.20	3.20	0.70
Raffinose	0.50	1.40	0.10	8.70	2.70	0.00	0.00	0.00	0.00	5.50	0.50
Stachyose	0.00	0.00	0.00	48.5	3.80	0.00	0.00	0.00	0.00	0.00	0.70
Verbascose	0.00	0.00	0.00	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Starch	645.0	695.4	672.8	10.2	0.00	55.7	56.0	119.3	222.0	192.7	0.00
Neutral detergent fibre [g/kg]	138.3	106.5	109.9	74.1	244.2	240.0	224.8	415.7	431.9	365.2	590.0
Acid detergent fibre [g/kg]	38.7	36.2	50.2	59.3	189.9	79.3	85.2	153.3	121.4	118.1	433.1
Lignin [g/kg]	6.20	7.80	5.80	3.10	64.5	7.40	7.50	24.4	9.70	37.3	18.5
Bulk density [g/l]	749	772	787	774	583	534	562	643	257	335	441
Particle size [μm]	448 ± 2	736 ± 2	805 ± 2	786 ± 2	597 ± 2	619 ± 1	301 ± 2	620 ± 2	920 ± 1	553 ± 2	549 ± 2
Water binding capacity [g/g]	1.29	1.15	1.11	2.93	3.18	1.94	1.94	3.67	3.13	4.06	5.05

Table 3. Analysed amino acid (AA) composition of corn, wheat, sorghum, soybean meal (SBM), canola meal, conventional distillers' dried grains with solubles (DDGS-CV), low fat distillers' dried grains with solubles (LF-DDGS), corn germ meal (CGM), corn bran, wheat middlings and soybean hulls [as-fed basis].

	Ingredients										
	Corn	Wheat	Sorghum	SBM	Canola meal	DDGS-CV	LF-DDGS	CGM	Corn bran	Wheat middlings	Soybean hulls
Indispensable AA [g/kg]											
Arg	3.90	5.40	3.10	34.2	21.1	11.5	12.4	16.3	3.80	11.7	4.10
His	2.30	2.50	1.90	12.7	9.50	7.00	7.80	6.80	3.30	4.50	2.50
Ile	2.80	3.60	3.50	22.4	14.2	10.0	11.0	8.50	3.10	5.20	3.40
Leu	9.60	6.90	11.8	37.1	25.1	31.0	34.0	18.2	11.1	10.3	5.70
Lys	2.80	3.50	1.90	30.4	20.5	8.90	10.7	9.70	2.80	7.50	6.20
Met	1.80	1.70	1.40	6.40	7.00	5.10	5.80	4.20	1.50	2.40	0.90
Phe	3.90	4.50	4.50	24.3	13.9	12.9	14.1	10.5	4.50	6.30	3.40
Thr	2.80	3.10	2.70	17.9	14.9	10.0	10.8	8.50	3.70	5.30	3.10
Trp	0.60	1.30	0.50	6.20	4.40	1.80	1.80	1.60	0.60	1.60	0.60
Val	3.90	4.80	4.50	24.0	18.6	13.3	14.4	13.6	4.60	7.80	4.30
Dispensable AA [g/kg]											
Ala	5.90	3.90	8.10	20.4	15.4	18.2	20.7	14.3	6.30	7.90	3.80
Asp	5.30	5.40	5.60	52.8	25.1	16.2	18.9	16.8	5.10	11.8	7.90
Cys	1.70	2.30	1.30	6.30	8.20	4.90	5.60	3.10	2.00	3.00	1.40
Glu	14.2	26.2	17.1	81.4	56.3	36.2	44.2	30.0	15.5	27.7	9.20
Gly	3.10	4.40	2.80	19.9	17.4	10.1	11.2	12.7	3.90	8.80	8.20
Pro	6.80	8.80	7.00	23.7	21.1	20.1	23.6	11.5	9.60	9.80	4.50
Ser	3.80	4.60	3.80	20.5	13.0	11.8	13.5	9.00	4.00	6.60	4.50
Tyr	2.70	2.90	3.10	17.7	9.90	10.5	11.0	6.90	3.10	4.40	3.80
Total AA [g/kg]	77.9	95.8	84.6	458.3	315.6	239.5	271.5	202.2	88.5	142.6	77.5

Table 4. Composition of experimental diets containing corn, wheat, sorghum, soybean meal (SBM), canola meal, conventional distillers' dried grains with solubles (DDGS-CV), low-fat distillers' dried grains with solubles (LF-DDGS), corn germ meal (CGM), corn bran, wheat middlings and soybean hulls [as-fed basis].

	Diets										
Ingredients [%]	Corn	Wheat	Sorghum	SBM	Canola meal	DDGS-CV	LF-DDGS	CGM	Corn bran	Wheat middlings	Soybean hulls
Corn	97.10	–	–	72.06	60.95	45.94	45.80	57.51	57.58	57.90	57.60
Wheat	–	97.69	–	–	–	–	–	–	–	–	–
Sorghum	–	–	97.20	–	–	–	–	–	–	–	–
SBM	–	–	–	25.50	–	–	–	–	–	–	–
Canola meal	–	–	–	–	37.00	–	–	–	–	–	–
DDGS-CV	–	–	–	–	–	52.00	–	–	–	–	–
LF-DDGS	–	–	–	–	–	–	52.00	–	–	–	–
Corn germ meal	–	–	–	–	–	–	–	40.00	–	–	–
Corn bran	–	–	–	–	–	–	–	–	40.00	–	–
Wheat middlings	–	–	–	–	–	–	–	–	–	40.00	–
Soybean hulls	–	–	–	–	–	–	–	–	–	–	40.00
Ground limestone	0.95	1.25	1.00	0.94	0.55	1.36	1.35	1.24	0.47	1.40	0.35
Monocalcium phosphate	1.25	0.36	1.10	0.80	0.80	–	0.15	0.55	1.25	–	1.35
NaCl	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix*	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Notes: *Provided per kilogram of complete diet: vitamin A as retinyl acetate, 3.34 mg; vitamin D_3 as cholecalciferol, 0.055 mg; vitamin E as DL-alpha tocopheryl acetate, 59.4 mg; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D -calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as $CuSO_4$ and $CuCl_2$; Fe, 126 mg as $FeSO_4$; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as $MnSO_4$; Se, 0.3 mg as Na_2SeO_3 and selenium yeast; and Zn, 125.1 mg as $ZnSO_4$.

Table 5. Chemical composition of experimental diets containing corn, wheat, sorghum, soybean meal (SBM), canola meal, conventional distillers' dried grains with solubles (DDGS-CV), low-fat distillers' dried grains with solubles (LF-DDGS), corn germ meal (CGM), corn bran, wheat middlings, or soybean hulls [as-fed basis].

	Diets										
	Corn	Wheat	Sorghum	SBM	Canola meal	DDGS-CV	LF-DDGS	CGM	Corn bran	Wheat middlings	Soybean hulls
Gross energy [MJ/kg]	15.75	15.75	15.73	16.18	16.27	17.69	17.11	15.98	16.33	15.96	15.60
Dry matter [g/kg]	879.0	886.0	873.0	884.0	887.0	889.0	888.0	891.0	895.0	882.0	894.0
Crude protein [g/kg]	85.2	108.0	84.6	200.0	193.0	187.0	196.0	138.0	85.6	116.0	91.4
Ether extract* [g/kg]	26.8	15.9	22.8	21.5	24.9	76.1	49.3	18.4	33.9	37.2	43.7
Ash [g/kg]	36.1	37.1	39.9	47.9	61.1	51.5	53.0	37.4	28.1	43.1	44.0
Carbohydrates [g/kg]											
Glucose	–	–	–	4.80	–	–	–	–	–	–	4.80
Fructose	–	–	–	5.40	–	–	–	–	–	–	8.30
Sucrose	–	–	–	24.0	–	–	–	–	–	–	6.10
Maltose	–	–	–	1.20	–	–	–	–	–	–	1.10
Raffinose	–	–	–	1.60	–	–	–	–	–	–	0.50
Stachyose	–	–	–	2.60	–	–	–	–	–	–	0.30
Verbascose	–	–	–	<0.01	–	–	–	–	–	–	<0.01
Neutral detergent fibre [g/kg]	135.6	104.3	99.8	118.2	179.0	193.6	177.6	237.4	250.2	217.0	301.8
Acid detergent fibre [g/kg]	38.0	35.7	48.2	40.7	102.7	66.2	70.2	79.1	72.3	68.6	198.6

Note: *Acid hydrolysed.

individual crates. On day 15, pigs and sows were moved into metabolism crates and day 15 to 19 was an adaptation period to the metabolism crates.

2.2. Sample collection

A colour marker was included in the meal provided on the morning of day 20 (chromic oxide) and again in the morning meal on day 24 (ferric oxide). Faecal samples were collected quantitatively from each pig according to the marker to marker procedure (Adeola 2001) with collections starting when the marker first appeared in the faeces after day 20 and collections ceasing when the marker first appeared after day 24. Faecal samples were stored at −20°C as soon as collected. Urine collection was initiated on day 20 in the morning and ceased on day 24, in the morning. Urine was collected in urine buckets over a preservative of 50 ml of 3 *N* HCl. Buckets were emptied once daily, the weights of the collected urine were recorded and 20% of the urine was stored at −20°C. At the conclusion of the experiment, urine samples were thawed and mixed and subsamples were taken. Faecal samples were also thawed and mixed and subsamples were collected for chemical analyses. Faecal subsamples were oven dried and finely ground prior to analyses.

2.3. Chemical analysis and calculations

Gross energy was determined in all samples using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL). Benzoic acid was used as the standard for calibration. Urine subsamples were prepared for GE analysis as previously outlined (Kim et al. 2009). Concentrations of acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined in ingredients, diets and faecal samples using Method 973.18 Holst (1973) and AOAC (2007), respectively. Both the SBM diet and the soy hulls diet were analysed for raffinose, stachyose, glucose, verbascose, maltose, sucrose and fructose (Cervantes-Pahm and Stein 2010). All ingredients were also analysed for monosaccharides, sucrose and oligosaccharides (Cervantes-Pahm and Stein 2010), for amino acids (Method 982.30 E [a, b, c]; AOAC 2007), Ca, P, Cu, Fe, Mg, Mn, K, Se, Na, S, Zn and Cl (Method 975.03; AOAC 2007) and total starch and lignin (Method 76–13; AACC Int. 2000; Method 973.18 (A-D); AOAC Int. 2006). The bulk density (Cromwell et al. 2000), particle size (ANSI/ASAE 2008) and water holding capacity (Urriola et al. 2010) of each ingredient was determined as well. For particle size, the feedstuff material in each of the test sieves was recorded and weighed for calculations of particle size distribution and mean particle size. After determination of the mean particle size as described by ANSI/ASAE (2008), the surface area was calculated using mean particle size of the grain as a reference (ANSI/ASAE 2008).

Samples of all ingredients, all diets and faeces were analysed for DM by oven drying at 135°C for 2 h (Method 930.15; AOAC Int. 2007) and for dry ash (Method 942.05; AOAC 2007). Concentrations of CP were analysed in samples of ingredients, diets and faeces using a 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. The concentration of acid hydrolysed ether extract (AEE) in ingredients and diets was analysed (Method 2003.06; AOAC 2007) on a Soxtec 2050 automated analyser (FOSS North America, Eden Prairie, MN).

2.4. Statistical analysis

The ATTD of energy, CP, ADF and NDF and the concentrations of DE and ME in each diet were calculated (NRC 2012). Methane emission was not taken into account for the ME calculation. Data were analysed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Outliers were tested using the UNIVARIATE procedure. Data were analysed separately for the three grain diets based on corn, wheat or sorghum; the four protein diets based on corn and SBM, canola meal, DDGS-CV or LF-DDGS; and the four high fibre diets based on corn and CGM, corn bran, WM or SBH. The model used to analyse each group of diets included diet, physiological stage and the interaction between diet and stage as the fixed effect and period as the random effect. Animal was used as the experimental unit for all analyses. Least squares means were calculated using the LSMeans procedure in SAS. The PDIFF option was used to separate means. An alpha level of 0.05 was used to assess significance among means and *p*-values between 0.05 and 0.10 were considered a trend.

Correlation coefficients between chemical components and ATTD of GE, CP, ADF and NDF and between chemical components and DE and ME concentration in the 11 diets were determined using PROC CORR (SAS Inst. Inc., Cary, NC). Prediction equations were developed by PROC REG to estimate the ATTD of GE, CP, ADF and NDF of gestating sows by the values from growing pigs (Sulabo and Stein 2013).

3. Results

The ATTD of GE and CP and the DE concentration in the wheat diet were greater ($p < 0.05$) than in the corn diet and the sorghum diet, and the DE and ME concentration (DM-basis) in the wheat diet were also greater than in the corn diet, but was not different from the sorghum diet (Table 6). There was no difference in ATTD of GE and CP, DE and ME concentration between the corn diet and the sorghum diet.

Gestating sows had greater ($p < 0.05$) ATTD of GE and CP and greater DE and ME in all grain diets than growing pigs. The ATTD of NDF was greater ($p < 0.05$) in sows than in growing pigs when they were fed the corn diet, less ($p < 0.05$) in sows than in growing pigs when they were fed the wheat diet, but not different between growing pigs and sows when they were fed the sorghum diet (interaction, $p < 0.05$). There was no diet effect for the ME:DE ratio, but there was a tendency ($p = 0.07$) for a greater ME:DE ratio in sows than in growing pigs.

Gestating sows had greater ($p < 0.05$) ATTD of GE and CP and greater DE than growing pigs when they were fed the four protein diets (Table 7). The ATTD of GE and CP was greater ($p < 0.05$) in the SBM diet than in other diets, and the ATTD of CP was greater ($p < 0.05$) in the DDGS-CV diet and the LF-DDGS diet than in the canola meal diet. The concentrations of DE and ME (as-fed and DM basis) in the canola meal diet were less ($p < 0.05$) than in all other diets. The ATTD of ADF was greater ($p < 0.05$) in growing pigs than in gestating sows when they were fed the SBM diet, but this was not the case when they were fed the canola meal diet, the DDGS-CV diet or the LF-DDGS diet (interaction, $p < 0.05$). The ATTD of NDF was less ($p < 0.05$) in growing pigs than in gestating sows if they were fed the DDGS-CV diet or the LF-DDGS diet, but not different between growing pigs and sows when they were fed the SBM diet or the canola meal diet (interaction, $p < 0.05$). No diet effect was observed for the ME:DE ratio, but gestating sows had less ($p < 0.05$) ME:DE ratio than growing pigs if fed the four protein diets.

Table 6. Comparative digestive utilisation of energy and nutrients in corn, wheat and sorghum diets by gestating sows and growing pigs*.

	Corn		Wheat		Sorghum			*p*-Value		
	Sows	Pigs	Sows	Pigs	Sows	Pigs	SEM†	Diet	Stage	Diet × Stage
Apparent total tract digestibility [%]										
Gross energy	88.23	85.84	90.85	89.26	88.88	85.94	1.09	<0.01	<0.01	0.70
Crude protein	80.90	62.64	90.38	82.73	73.30	61.70	3.51	<0.01	<0.01	0.24
Acid detergent fibre	65.25	62.56	44.29	53.20	67.89	70.90	4.83	<0.01	0.73	0.10
Neutral nutrient fibre	79.71[a]	70.96[bc]	61.98[d]	68.97[c]	79.44[a]	74.67[ab]	2.45	<0.01	0.23	<0.01
Digestible energy (DE) [MJ/kg]										
as-fed basis	13.90	13.52	14.31	14.06	13.98	13.52	0.17	<0.01	<0.01	0.71
Dry matter basis	15.82	15.39	16.14	15.86	16.02	15.49	0.20	<0.05	<0.01	0.70
Metabolisable energy (ME) [MJ/kg]										
as-fed basis	13.49	12.71	13.79	13.44	13.72	12.94	0.21	<0.05	<0.01	0.33
Dry matter basis	15.35	14.46	15.56	15.16	15.72	14.83	0.24	<0.05	<0.01	0.33
ME/DE [%]	97.05	93.86	96.37	95.45	96.94	95.56	1.34	0.76	0.07	0.53

Notes: *Data are means of eight observations; †SEM, Standard error of the mean; [a-c]Least square means within a row with different superscript letters are significantly different ($p < 0.05$).

Table 7. Comparative digestive utilisation of energy and nutrients in diets containing soybean meal (SBM), canola meal (CM), conventional distillers' dried grains with solubles (DDGS-CV), or low-fat distillers' dried grains with solubles (LF-DDGS) by gestating sows and growing pigs*.

	SBM		CM		DDGS-CV		LF-DDGS			*p*-Value		
	Sows	Pigs	Sows	Pigs	Sows	Pigs	Sows	Pigs	SEM[†]	Diet	Stage	Diet × Stage
Apparent total tract digestibility [%]												
Gross energy	87.40	87.22	81.06	80.48	82.48	78.59	82.37	80.56	1.20	<0.01	<0.05	0.17
Crude protein	88.46	86.48	82.68	77.61	85.43	81.07	85.36	80.62	1.45	<0.01	<0.01	0.58
Acid detergent fibre	59.69[bc]	67.29[a]	44.00[e]	47.78[de]	58.49[bc]	54.01[cd]	61.41[ab]	64.49[ab]	3.25	<0.01	0.19	<0.05
Neutral nutrient fibre	75.79[a]	72.94[a]	55.12[cd]	61.67[bc]	63.74[b]	50.58[d]	61.21[bc]	54.31[d]	3.09	<0.01	<0.05	<0.01
Digestible energy (DE) [MJ/kg]												
as-fed basis	13.98	14.08	13.18	13.06	14.59	13.88	14.10	13.76	0.21	<0.01	0.05	0.08
Dry matter basis	15.81	15.93	14.87	14.74	16.42	15.62	15.88	15.50	0.24	<0.01	0.05	0.08
Metabolisable energy (ME) [MJ/kg]												
as-fed basis	13.24	13.40	12.34	12.42	13.72	13.15	13.24	13.40	0.30	<0.01	0.83	0.35
Dry matter basis	14.98	15.16	13.92	14.01	15.44	14.80	14.92	15.09	0.34	<0.01	0.83	0.35
ME/DE [%]	94.70	95.09	94.30	96.57	93.99	97.40	93.92	97.05	0.72	0.73	<0.01	0.17

Notes: *Data are means of eight observations; [†]SEM, Standard error of the mean; [a-e]Least square means within a row lacking a common superscript letter are significantly different ($p < 0.05$).

The ATTD of CP was greater ($p < 0.05$) in sows than in growing pigs if fed the high fibre diets (Table 8). The ATTD of CP was greatest ($p < 0.05$) in the WM diet, least ($p < 0.05$) in the SBH diet and intermediate in the CGM and corn bran diets. The ATTD of GE was greater ($p < 0.05$) in sows than in growing pigs when they were fed the WM diet or the SBH diet, but not different between sows and growing pigs when they were fed the CGM diet or the corn bran diet (interaction, $p < 0.05$). The ATTD of ADF was greater ($p < 0.05$) in growing pigs than in sows when they were fed the CGM diet and the ATTD of ADF and NDF was less ($p < 0.05$) in growing pigs than in sows when they were fed the SBH diet, but no difference between growing pigs and sows was observed for the corn bran and the WM diets (interaction, $p < 0.05$). Digestible energy and ME concentrations in the WM diet and the SBH diet were greater ($p < 0.05$) in sows than in growing pigs, but the DE and ME values of the CGM diet and the corn bran diet were not different between sows and growing pigs (interaction, $p < 0.05$). However, there was no diet or stage effect on the ME:DE ratio.

The ATTD of GE and CP and the DE values for gestating sows may be directly predicted from the values obtained in growing pigs and the R^2 for these equations were 0.77, 0.73 and 0.77, respectively (Table 9). However, the R^2 of prediction equations for ATTD of ADF and NDF and the ME values for gestating sows were 0.27, 0.41 and 0.55, respectively.

The concentrations of ADF and NDF in the diets were negatively correlated ($p < 0.05$) with the ATTD of GE and the DE and ME values in both gestating sows and growing pigs (Table 10). The concentrations of ADF and NDF were negatively correlated ($p < 0.05$) with the ATTD of CP in gestating sows, but this was not the case for growing pigs. The concentration of CP in the diets was positively correlated ($p < 0.05$) with the ATTD of CP in growing pigs, but the concentration of AEE in the diets was negatively correlated ($p < 0.05$) with the ATTD of GE and NDF in growing pigs.

4. Discussion

Concentrations of GE, DE, ME, DM, CP, AEE and ash of all 11 ingredients were close to expected values (Sauvant et al. 2004; Baker and Stein 2009; Kim et al. 2009; Urriola et al. 2010; NRC 2012; Rojas et al. 2013; Stewart et al. 2013). Corn, wheat and sorghum contained more starch than the four protein concentrates and the four high fibre ingredients, and the per cent of starch in corn, wheat and sorghum is in agreement with published values (NRC 2012; Rosenfelder et al. 2013). Soybean meal, canola meal, DDGS-CV and LF-DDGS contained more CP than the three cereal grains and the four high fibre ingredients, and these values are in agreement with previously reported data (Stein et al. 1999, 2006, 2009; Pahm et al. 2008; Goebel and Stein 2011; González-Vega and Stein 2012; Kim et al. 2012; NRC 2012; Rodríguez et al. 2013; Rojas et al. 2013). Both sources of DDGS contained more AEE than the other nine ingredients, which is in agreement with published data (Sauvant et al. 2004; NRC 2012). The two sources of DDGS contained 122 and 80 g/kg AEE, respectively. A concentration of AEE of 122 g/kg is in agreement with expected values for DDGS-CV, and a concentration of 80 g/kg is within the range of values observed in low-fat corn DDGS that has fat skimmed off the solubles (Anderson et al. 2012; NRC 2012; Kerr et al. 2013). Corn germ meal, corn bran, WM and SBH contained more ADF and NDF than the other seven ingredients.

The observation that the ATTD of GE and CP, as well as DE and ME concentration of diets is greater in gestating sows fed at approximately 1.5 times the maintenance requirement for energy than in growing pigs fed close to the *ad libitum* intake is in agreement

Table 8. Comparative digestive utilisation of energy and nutrients in diets containing corn germ meal (CGM), corn bran, wheat middlings, or soybean hulls by gestating sows and growing pigs*.

	CGM		Corn bran		Wheat middlings		Soybean hulls			*p*-Value		
	Sows	Pigs	Sows	Pigs	Sows	Pigs	Sows	Pigs	SEM†	Diet	Stage	Diet × Stage
Apparent total tract digestibility [%]												
Gross energy	82.73^{ab}	83.94^{a}	79.45^{bcd}	79.23^{bcd}	84.13^{a}	78.91^{cd}	80.75^{abc}	75.76^{d}	1.53	<0.01	<0.05	<0.05
Crude protein	74.31	69.72	71.53	70.22	82.98	71.36	63.09	57.53	2.58	<0.01	<0.01	0.20
Acid detergent fibre	69.03^{b}	77.93^{a}	51.18^{cd}	56.64^{c}	47.99^{d}	48.38^{d}	91.31^{a}	57.65^{c}	2.86	<0.01	0.28	<0.01
Neutral nutrient fibre	77.71^{a}	82.23^{a}	52.39^{c}	59.11^{bc}	61.37^{b}	62.51^{b}	81.60^{a}	63.22^{b}	2.66	<0.01	0.44	<0.01
Digestible energy (DE) [MJ/kg]												
as-fed basis	13.22^{a}	13.41^{a}	12.98^{ab}	12.94^{ab}	13.42^{a}	12.59^{b}	12.59^{b}	11.82^{c}	0.24	<0.01	<0.05	<0.05
Dry matter basis	14.85^{abc}	15.06^{ab}	14.50^{bcd}	14.46^{bcd}	15.22^{a}	14.27^{cd}	14.10^{d}	13.23^{e}	0.27	<0.01	<0.05	<0.05
Metabolisable energy (ME) [MJ/kg]												
as-fed basis	12.59^{ab}	12.91^{a}	12.55^{abc}	12.33^{abc}	12.95^{a}	11.92^{cd}	12.23^{bc}	11.31^{d}	0.26	<0.01	<0.05	<0.05
Dry matter basis	14.14^{ab}	14.50^{a}	14.03^{ab}	13.78^{b}	14.67^{a}	13.51^{b}	13.69^{b}	12.66^{c}	0.29	<0.01	<0.05	<0.05
ME/DE [%]	95.20	96.51	96.72	96.50	96.40	95.67	97.11	96.31	0.96	0.68	0.87	0.55

Notes: *Data are means of eight observations; †SEM, Standard error of the mean; a-dLeast square means within a row lacking a common superscript letter are different ($p < 0.05$).

Table 9. Prediction of apparent total tract digestibility (ATTD) of gross energy (GE), crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), and for digestible energy (DE) and metabolisable energy (ME) of diets for gestating sows from values in growing pigs*.

		Standard error		*p*-Value				
Dependent variable	Prediction equation	Intercept	Estimate	Intercept	Estimate	R^2	RMSE	*p*-Value
ATTD of GE_{sow} [%]	20.490 + 0.776 · ATTD of GE_{pig} [%]	11.72	0.78	0.11	<0.01	0.77	1.93	<0.01
ATTD of CP_{sow} [%]	25.989 + 0.739 · ATTD of CP_{pig} [%]	11.11	0.74	<0.05	<0.01	0.73	4.58	<0.01
ATTD of ADF_{sow} [%]	15.334 + 0.744 · ATTD of ADF_{pig} [%]	25.03	0.41	0.56	0.10	0.27	12.38	0.10
ATTD of NDF_{sow} [%]	20.008 + 0.735 · ATTD of NDF_{pig} [%]	19.50	0.29	0.33	<0.05	0.41	8.74	<0.05
DE_{sow} [MJ/kg DM]	3.237 + 0.810 · DE_{pig} [MJ/kg DM]	2.23	0.15	0.18	<0.01	0.77	0.38	<0.01
ME_{sow} [MJ/kg DM]	5.080 + 0.675 · ME_{pig} [MJ/kg DM]	2.92	0.20	0.12	<0.01	0.55	0.51	<0.01

Note: *A total of 11 diets were used.

Table 10. Correlation coefficients between chemical components and apparent total tract digestibility (ATTD) of energy and nutrients and digestible energy (DE) and metabolisable energy (ME) in 11 diets fed to growing pigs or gestating sows [DM basis][#].

	Correlation coefficient (*r*)					
	GE[†] [MJ/kg]	CP[‡] [g/kg]	AEE[◊] [g/kg]	Ash [g/kg]	ADF[♦] [g/kg]	NDF[+] [g/kg]
Sows						
ATTD of GE [%]	−0.27	−0.20	−0.40	−0.21	−0.64*	−0.85**
ATTD of CP [%]	0.45	0.60	0.29	0.38	−0.70*	−0.67*
ATTD of ADF [%]	−0.26	−0.28	−0.19	−0.12	0.60*	0.40
ATTD of NDF [%]	−0.42	−0.29	−0.45	−0.18	0.15	−0.09
DE [MJ/kg DM]	0.52	0.31	0.36	0.18	−0.75**	−0.81**
ME [MJ/kg DM]	0.30	−0.003	0.18	−0.06	−0.75**	−0.82**
Growing pigs						
ATTD of GE [%]	−0.26	−0.04	−0.50*	−0.24	−0.74**	−0.85**
ATTD of CP [%]	0.56	0.78**	0.39	0.43	−0.47	−0.40
ATTD of ADF [%]	−0.13	−0.05	−0.30	−0.29	−0.19	−0.15
ATTD of NDF [%]	−0.68*	−0.32	−0.80**	−0.40	−0.22	−0.29
DE [MJ/kg DM]	0.42	0.41	0.14	0.10	−0.86**	−0.85**
ME [MJ/kg DM]	0.43	0.44	0.14	0.12	−0.81**	−0.81**

Notes: [#]A total of 11 diets were used; [†]GE, Gross energy; [‡]CP, Crude protein; [◊]AEE, Ether extract, acid hydrolysed; [♦]ADF, Acid detergent fibre; [+]NDF, Neutral detergent fibre.
*$p < 0.05$, **$p < 0.01$.

with results of several previous experiments from Europe (Fernández et al. 1986; Shi and Noblet 1993a; Le Goff and Noblet 2001; Cozannet et al. 2010). These results are the reason feed ingredients in Europe often are assigned separate energy values for growing pigs and sows (Sauvant et al. 2004). However, this effect has not been previously demonstrated in North America, which is why feed ingredients in North America are assigned a common energy value for both sows and growing pigs (NRC 2012). However, the current results support the observations from Europe and indicate that gestating sows fed at 1.5 times their maintenance energy requirement digest energy and nutrients to a greater extent than growing pigs allowed *ad libitum* access to feed.

The increased digestibility of energy by gestating sows compared with growing pigs may be a result of differences in age, BW and feeding level (Cunningham et al. 1962; Everts et al. 1986; Bridges et al. 1988; Stein et al. 2001). Adult animals have greater BW, which correlates to a larger, more developed intestinal tract and thus, greater intestinal volume (Bridges et al. 1986; Dierick et al. 1989; Brunsgaard 1997). An increased intestinal volume may influence digestibility through a decreased rate of passage allowing for more exposure of feed to enzymes and bacteria and more absorption of nutrients in the small and large intestine (Cunningham et al. 1962; Fernández et al. 1986; Varel 1987; Dierick et al. 1989; Low 1993). Some of the largest differences in digestibility result from greater hindgut activity of sows, which contributes to total digestibility of nutrients (Fernández et al. 1986; Shi and Noblet 1993a). A reduction in feeding level also increases digestibility of energy and nutrients in sows (Cunningham et al. 1962; Everts et al. 1986; Shi and Noblet 1993a). However, results of this experiment indicate that the increased energy obtained by sows compared with growing pigs was not a result of increased fermentation of fibre. Gestating sows were fed approximately 1.5 times their maintenance requirement, whereas growing pigs were fed 3.4 times their maintenance requirement.

These levels are similar to previous studies (Fernández et al. 1986; Noblet and Shi 1993; Shi and Noblet 1993a, 1993b) and also close to feeding levels used in commercial production. The time of adaptation to diets varies among studies but does not appear to have an effect on differences in digestibility between sows and growing pigs. Sows had greater total tract digestibility of nutrients than growing pigs if adapted for 5 d (Fernández et al. 1986), 10 d (Le Goff and Noblet 2001), 12 d (Shi and Noblet 1993b) or 17 d (Shi and Noblet 1993a). However, the length of time we allowed the animals to adapt to their diets was longer in this experiment compared with previous experiments because both gestating sows and growing pigs were allowed 19 d to adapt to their respective diets before faecal collections were initiated. It is possible that with a longer adaptation, growing pigs were able to adapt to the fibre and, therefore, ferment the fibre, as well as the sows. Previous data indicate that pigs adapt to longer periods of feeding fibrous material through an increase in fermentation (Gargallo and Zimmerman 1981; Wenk 2001). This increase in fermentation may be due to an increase in hindgut size in the growing pigs. A longer adaptation time allows for increased BW and further development of the digestive tract (Bridges et al. 1986). As BW increases, overall weight of the digestive tract increases, resulting in decreased rate of passage and increased digestibility of nutrients (Bridges et al. 1986; Varel 1987). An increase in hindgut microbial mass may be developed with a longer adaptation time to high fibre diets (Varel 1987), which likely contributed to increased fermentation in growing pigs.

It was surprising that the ATTD of ADF in SBM and CGM and the NDF in wheat was less in gestating sows than in growing pigs. It is possible that this is due to differences in the composition of the fibre among ingredients, but we did not analyse for fibre composition and, therefore, do not have data to support this speculation. However, the observation that the presence of fibre in the diets negatively affects the digestibility of energy and CP was expected and is consistent with previous reports (Nyachoti et al. 1997; Yin et al. 2000; Wilfart et al. 2007). The main reason fibre negatively affects digestibility of energy and CP in both gestating sows and growing pigs is an increase in endogenous losses in the form of losses of mucin because endogenous losses are influenced by diet composition and increase with an increase in dietary fibre (Stein et al. 2007). However, high fibre diets also will increase synthesis of microbial protein, which will increase excretion of CP in the faeces and thus reduce total tract digestibility of CP (Varel 1987; Zervas and Zijlstra 2002). High dietary fibre may also diminish the efficiency of digestion as it increases the flow of nutrients or rate of passage (Fernández et al. 1986; Wenk 2001; Serena et al. 2008).

Although we observed differences in digestibility of energy and CP between gestating sows and growing pigs, values for the ATTD of GE and CP and DE for sows can be directly predicted from the values obtained in growing pigs. However, more accurate prediction equations can be used to estimate the digestibility of energy and CP and the concentration of DE and ME in the diets from the concentration of nutrients and GE in the feed ingredients.

5. Conclusions

The apparent digestibility values of CP obtained in gestating sows are greater than values obtained in growing pigs, regardless of type of diet. The values for ATTD of GE and DE obtained in gestating sows were greater than values obtained in growing pigs for the grain and protein diets. The values for ME obtained in gestating sows were greater than values obtained in growing pigs for the three grain diets, but were not different for the four protein diets. Overall, there were no differences in fibre digestibility between gestating sows and growing pigs. However, among the individual high fibre diets, gestating sows had greater digestibility of ADF and NDF than growing pigs for the SBH diet, but growing pigs had greater ATTD of ADF for the CGM diet. Differences in digestibility of energy between gestating sows and growing pigs indicate that different energy values for gestating sows and growing pigs should be considered when formulating diets. Values for the ATTD of GE and CP and the DE in diets fed to gestating sows may be estimated from values obtained in growing pigs by using prediction equations.

Disclosure statement

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