RESEARCHREPORT
ANIMAL SCIENCE

Title: Comparative Digestibility of energy and nutrients in gestating sows and growing pigs – **NPB #12-180**

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Date Submitted: March 7, 2014

Industry Summary

The objective of this research was to compare DE and ME values and values for the apparent total tract digestibility (**ATTD**) of energy and nutrients of the 11 diets in growing pigs and gestating sows. Two experiments were conducted to determine digestibility of energy and ATTD of nutrients for diets containing corn, wheat, sorghum, SBM, canola meal, conventional distillers dried grains with solubles (**DDGS**), low-fat DDGS, corn germ meal, corn bran, wheat middlings, or soybean hulls in growing pigs and gestating sows. Results indicated that apparent digestibility values of energy and CP, and DE and ME values obtained in gestating sows are greater than values obtained in growing pigs, but apparent digestibility of fiber obtained in growing pigs is not different from values obtained in gestating sows. Pork producers can take advantage of the results from this research when formulating diets for sows and growing pigs and prediction equations calculated from this work may assist in formulating diets for gestating sows.

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Keywords: digestibility, energy, fiber, gestating sows, growing pigs

Scientific Abstract

The objective of this research was to compare DE and ME values and ATTD of energy and nutrients in 11 diets fed to both growing pigs and gestating sows. Eleven feed ingredients were used. Three ingredients were cereal grains (corn, sorghum, and wheat), 4 were common protein sources [soybean meal, canola meal, distillers dried grains with solubles (DDGS), and low-fat DDGS], and 4 were high-fiber ingredients (corn germ meal, corn bran, wheat middlings, and soybean hulls). Eleven diets were formulated. Three 3 diets were based on corn, wheat, or sorghum, and 8 diets were based on a combination of corn and each of the remaining 8 ingredients. A total of 88 gestating sows (parity 2 to 6) and 88 growing barrows (40.1 ± 4.69 kg BW) were used and randomly allotted to the 11 diets with 8 replicates per diet. Fecal and urine samples were collected for 4 d following a 19-d adaptation period. The DE, ME, and ATTD of ADF, NDF, and CP in all diets were calculated. Gestating sows had greater ($P < 0.05$) ATTD of GE and CP, and DE values (as-fed and DM basis) for all diets compared with growing pigs. Gestating sows had greater ($P < 0.05$) ME values (as-fed and DM basis) for grain diets and protein source diets than growing pigs. No differences were observed in ATTD of ADF and NDF between gestating sows and growing pigs for any of the diets. The ATTD of GE and CP, and DE values in gestating sows may be directly predicted from the values obtained in growing pigs. For both gestating sows and growing pigs, prediction equations can be used to estimate ATTD of GE and CP, and DE and ME values in the diets from the concentrations of nutrients and GE. Results of this research indicate that apparent digestibility values of CP and energy obtained in gestating sows are greater than values obtained in growing pigs, but apparent digestibility of fiber obtained in growing pigs is not different from digestibilities in gestating sows.

Introduction:

Sows have a larger digestive tract than growing pigs; therefore, sows are able to ferment fiber in fiber rich ingredients better than growing pigs (Fernandez et al., 1986; Shi and Noblet, 1993a; Le Goff and Noblet, 2001). Sows also have greater apparent total tract digestibility (ATTD) of several nutrients compared with growing pigs (Fernandez et al., 1986). The reduced feeding level in gestating sows compared with growing pigs also contributes to an increase in ATTD of dietary nutrients and energy. Digestible energy and ME values of diets and feed ingredients are dependent on physiological stage/BW of the animal and/or feeding level (Shi and Noblet, 1993a). Total tract digestibility of all nutrients, except starch, is improved with increase in body size. This variation is most important for fiber-rich feeds (Noblet and Shi, 1994) and differences in DE are positively related to dietary fiber level (Le Goff and Noblet, 2001). Greater digestibility of energy and OM in sows is largely explained by their greater ability to ferment fiber (Shi and Noblet, 1993).

Although it has been reported from European experiments that DE, ME, and ATTD of nutrients is greater in gestating sows fed close to their maintenance requirement than in growing pigs allowed ad libitum access to their diets, no data from North America for the comparative ATTD of energy and nutrients have been reported. As use of high-fiber ingredients increases in the United States, such values are needed to accurately formulate diets for growing pigs and sows.

Objectives

The objective of this research was to test the hypothesis that ATTD of energy and nutrients and values for DE and ME are greater in gestating sows fed close to maintenance than for growing pigs allowed ad libitum access to feed.

Materials and Methods:

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

Eleven feed ingredients were used in the experiment. Three of the ingredients were cereal grains (corn, sorghum, and wheat), 4 ingredients were commonly used protein sources [soybean meal (**SBM**), canola meal, distillers dried grains with solubles (HF-**DDGS**), and low-fat DDGS (**LF-DDGS**)], and the remaining 4 ingredients were commonly used high-fiber ingredients [corn germ meal (**CGM**), corn bran, wheat middlings (**WM**), and soybean hulls (**SBH**)].

A total of 88 gestating sows (parity 2 to 6) 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, MN). 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 feces 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.

Eleven diets were formulated (Tables 2 and 3). Three diets were based on corn, sorghum, or wheat, and 8 diets were based on a combination of corn and each of the remaining 8 ingredients. Vitamins and minerals were included in all diets to meet current requirements (NRC, 2012). The same diets were fed to sows and to growing pigs. A randomized 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 8 blocks of 11 sows for a total of 8 replicate sows per diet and 4 blocks of 22 growing pigs which also resulted in a total of 8 replicates per diet.

Feed was provided daily in an amount of approximately 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 2 equal meals that were provided at 0700 and 1600 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 individual crates. On d 15, pigs and sows were moved into metabolism crates and d 15 to 19 was an adaptation period to the metabolism crates. A color marker was included in the meal provided in the morning of d 20 and again in the morning meal on d 24. Fecal samples were collected quantitatively according to the marker to marker procedure (Adeola, 2001) with collections starting when the marker first appeared in the feces after d 20 and ceased when the marker again appeared after d 24. Fecal samples were stored at -20^{o}C as soon as collected. Urine collection was initiated on d 20 in the morning and ceased on d 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^{o}C. Fecal samples were collected twice daily and stored at -20^{o}C. At the conclusion of the experiment, urine samples were thawed and mixed within animal. Fecal samples were thawed and mixed within animal and diet and subsamples were collected for chemical analysis.

Fecal subsamples were oven dried and finely ground prior to analysis. Samples of all ingredients, all diets, and feces were analyzed for DM by oven drying at 135°C for 2 h (Method 930.15; AOAC Int., 2007) and dry ash (Method 942.05; AOAC Int., 2007). Concentrations of CP were analyzed in samples of ingredients, diets, and feces using a combustion procedure (Method 990.03; AOAC Int., 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 hydrolyzed ether extract in ingredients and diets was analyzed (Method 2003.06; AOAC Int., 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). 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 samples were prepared for GE analysis as previously outlined (Kim et al., 2009). Concentrations of ADF and NDF were determined in ingredients, diets, and fecal samples using Method 973.18 (AOAC Int., 2007) and Holst (1973), respectively. Both the SBM diet and the soy hulls diet were analyzed for raffinose, stachyose, glucose, verbascose, maltose, sucrose, and fructose (Churns, 1982; Kakehi and Honda, 1989). All ingredients were also analyzed for monosaccharides, sucrose, and oligosaccharides (Cervantes-Pahm and Stein, 2010), for AA (Method 982.30 E [a, b, c]; AOAC Int., 2007), Ca, P, Cu, Fe, Mg, Mn, K, Se, Na, S, Zn, and Cl (Method 975.03; AOAC Int., 2007), total starch and lignin (Method 76-13; AACC Int., 2000; Method 973.18 (A-D); AOAC Int., 2006), and for phytic acid (Ellis et al., 1977). 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.

The ATTD of energy, CP, fat, ADF, NDF, and ash and the concentration of DE and ME in each diet was calculated (Adeola, 2001). Outliers were tested using the UNIVARIATE procedure. Data were analyzed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). Data were analyzed separately for the 3 grain diets based on corn, wheat, or sorghum, the 4 protein source diets based on corn and SBM, canola meal, HF-DDGS, or LF-DDGS, and the 4 high fiber diets based on corn and CGM, corn bran, WM, or SBH. The model included diet, physiological stage, and their interaction 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.

Correlation coefficients between chemical components and ATTD of GE, CP, ADF, and NDF, and between chemical components and DE and ME in the 11 diets were determined using PROC CORR (SAS Inst. Inc., Cary, NC). Prediction equations were developed by PROC REG as previously described (Sulabo and Stein, 2013). The best regression models were determined using multiple criteria analyses where the Conceptual predictive [**C(p)**] criterion, the coefficient of determination (**R^2**), Akaike information criterion (**AIC**), root mean square error (**RMSE**), and the *P*-value of the model were considered. The prediction equation with C(p) close to p, where p is the number of variables in the candidate model + 1, the least AIC, which is a measure of fit, and the least RMSE, which is a measure of precision, was considered the optimal model.

Results

The wheat diet had greater ($P < 0.05$) ATTD of GE, CP, and DE (as-fed) than the corn diet and the sorghum diet, and greater ($P < 0.05$) DE (DM basis) and ME (as-fed and DM basis) than the corn diet (Table 4). There was no difference in ATTD of GE, DE, and ME between the corn diet and the sorghum diet, but the corn diet had greater ($P < 0.05$) ATTD of CP than the sorghum diet. Gestating sows had greater ($P < 0.05$) ATTD of GE and CP, and DE and ME for grain diets than growing pigs. The ATTD of ADF was greater ($P < 0.05$) in pigs than in gestating sows if the wheat diet was provided, but not different between pigs and sows when if the corn or sorghum diet was fed (interaction, $P < 0.05$). The ATTD of NDF was greater ($P < 0.05$) in sows than in pigs when they were fed the corn diet, less ($P < 0.05$) in sows than in pigs when they were fed the wheat diet, but not different between pigs and sows when they were fed the sorghum diet (interaction, $P < 0.05$). No diet effect and stage effect were observed in ME/DE ratios among the 3 cereal grains.

Pigs and sows fed the SBM diet had greater ($P < 0.05$) ATTD of GE and CP than if they were fed the canola meal diet, HP-DDGS diet, or the LF-DDGS diet, and the ATTD of CP in the HF-DDGS diet and the LF-DDGS diet was greater ($P < 0.05$) than in the canola meal diet (Table 5). No difference was observed in ATTD of GE and CP between the HF-DDGS diet and the LF-DDGS diet. On both as-fed and DM basis, diets containing

SBM, HF-DDGS, or LF-DDGS had greater ($P < 0.05$) DE and ME than the canola meal diet, but no difference was observed in DE and ME among the SBM, HF-DDGS, and LF-DDGS diets. However, gestating sows had greater ($P < 0.05$) ATTD of GE and CP and DE than growing pigs regardless of the protein diets being fed. The ATTD of ADF was greater ($P < 0.05$) in growing pigs than in gestating sows if the SBM diet was provided, but that was not the case for the canola meal diet, HF-DDGS diet, or LF-DDGS diet (interaction, $P < 0.05$). The ATTD of NDF was greater ($P < 0.05$) in growing pigs than in gestating sows if the canola meal diet was provided, less ($P < 0.05$) in growing pigs than in gestating sows if the HF-DDGS diet was provided, but not different between pigs and sows if the SBM diet or the LF-DDGS diet was provided (interaction, $P < 0.05$). No diet effect or stage effect was observed for the ME/DE ratio.

Pigs and sows fed the CGM diet or the WM diet had greater ($P < 0.05$) ATTD of CP and ME/DE ratio than when they were fed the corn bran diet or the SBH diet, and the corn bran diet had greater ($P < 0.05$) ATTD of CP and ME/DE ratio than the SBH diet (Table 6). The ATTD of CP and the ME/DE ratio was greater ($P < 0.05$) in sows than in pigs. The ATTD of GE was greater ($P < 0.05$) in sows than in pigs when they were fed WM diet or SBH diet, but not different between sows and pigs when they were fed CGM diet and corn bran diet (interaction, $P < 0.05$). The ATTD of ADF was greater ($P < 0.05$) in pigs than in sows when they were fed the CGM diet and the ATTD of ADF and NDF was less ($P < 0.05$) in pigs than in sows when they were fed SBH diet, but no difference between pigs and sows was observed among the other diets (interaction, $P < 0.05$). On both an as-fed and a DM-basis, the DE and ME values of the WM and the SBH diets were greater ($P < 0.05$) in sows than in pigs, but the DE and ME values of CGM diet or corn bran diet were not different between sows and pigs (interaction, $P < 0.05$).

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 are 0.72 or 0.78 (Table 7). However, the R^2 of the prediction equations for ATTD of ADF and NDF and the ME values for gestating sows were less than 0.54.

The concentrations of ADF and NDF in the diets were negatively correlated ($P < 0.05$) with the ATTD of GE and CP and DE and ME values both in gestating sows and growing pigs (Table 8). 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.

The optimal models to predict ATTD of GE and CP, and DE and ME in sows were (Table 9):

ATTD of GE, % = 97.53 - 0.0248*CP - 0.0192*AEE - 0.0264*ADF - 0.0282*NDF (1);

ATTD of CP, % = 286.00 - 0.0503*GE + 0.1051*CP + 0.3434*AEE - 0.2018*NDF (2);

DE, kcal/kg DM = 2,750 + 0.3294*GE - 0.4031*CP + 2.9577*AEE - 2.7199*ash - 1.1788*ADF - 1.7808*NDF (3);

ME, kcal/kg DM = 3,361 + 0.1884*GE - 1.1757*CP + 3.2946*AEE - 3.3369*ash - 1.1621*ADF - 1.9782*NDF (4).

The optimal models to predict ATTD of GE and CP, and DE and ME in growing pigs were:

ATTD of GE, % = 101.34 + 0.0353*CP - 0.0563*AEE - 0.2833*ash - 0.0364*ADF (5);

ATTD of CP, % = 230.99 - 0.0209*GE + 0.1886*CP + 0.2043*AEE - 0.4122*ash - 0.0211*ADF - 0.0775*NDF (6);

DE, kcal/kg DM = - 860 + 1.2275*GE + 0.8246*CP – 5.3211*AEE – 10.8080*ash - 1.4293*ADF + 0.1322*NDF (7);

ME, kcal/kg DM = -1,740 + 1.3693*GE + 0.8217*CP – 7.3042*AEE – 8.9457*ash – 1.1202*ADF + 0.4537*NDF (8).

All of these models had $R^2 > 0.85$.

Discussion

The composition of the ingredients included in the experiment was in line with expectations (NRC, 2012). The 2 sources of DDGS contained 12.20 and 7.99% AEE, respectively. The concentration of 12.20% is in line with the expected concentration in DDGS-CV, whereas the concentration of 7.99% is in the range of values usually observed in low-fat corn DDGS that has had fat skimmed off the solubles (NRC, 2012). The concentration of AEE in CGM was less than in the low-fat DDGS, which is also as expected because CGM is produced by extracting the fat from corn germ (Rojas et al., 2013). The high concentration of NDF in the 4 high fiber diets confirms that these ingredients have a different nutritional profile than the other ingredients. As a consequence, diets containing CGM, WM, corn bran, or SBH contained more fiber than diets containing other ingredients.

The observation that the ATTD of GE and CP, and the DE and ME of diets were greater in sows than in pigs agrees with results from several European experiments, which have indicated that the ATTD of energy and nutrients is greater in sows than in growing pigs (Fernandez et al., 1986; Shi and Noblet, 1993; Le Goff and Noblet, 2001). However, we were not able to confirm that there is a difference in the digestibility of fiber between gestating sows and growing pigs. We do not have a definitive explanation for this observation. However, there are some differences in the methodologies used between the European experiments and the present experiment. First, we allowed both the pigs and the sows to adapt to their diets for approximately 20 days before we started fecal collections. This is a longer adaptation time than used in previous experiments and may have resulted in growing pigs being able to digest as well as sows. We also fed the sows at approximately 1.5 times the estimated requirement for maintenance rather than feeding at the maintenance requirement because we wanted to use a feeding level that is as close as possible to the feeding level used in commercial facilities. Third, we used different ingredients in our diets than in the previous studies, which may also have influenced the results. In addition, in some of the European experiments, ingredients with very high concentrations of fiber, such as barley straw, were included, which may be the reason differences in fiber digestibility were observed in the European experiments.

The observation that the presence of fiber in the diets negatively affects the digestibility of energy and CP is consistent with previous data (Nyachoti et al., 1997; Yin et al., 2000; Wilfart et al., 2007). This is mainly due to dietary fiber in the diets increases endogenous losses in both growing pigs and gestating sows.

Even though differences were observed in digestibility of energy and CP between sows and pigs, the ATTD of GE and CP, and DE values for sows could be directly predicted from the values obtained in pigs. This observation indicates that it may not always be necessary to determine the digestibility of nutrients and energy in sows – instead values may be predicted from data for growing pigs. It is also possible to predict these values from the composition of the ingredients.

Conclusions

The results of this research indicate that apparent digestibility values of CP and energy obtained in gestating sows are greater than values obtained in growing pigs, but apparent digestibility of fiber obtained in growing pigs is not different from values obtained in gestating sows. The DE and ME are also greater in sows than in growing pigs which means that it is not accurate to use values obtained in growing pigs when formulating diets for sows. However, values for sows can be predicted from values for growing pigs using prediction equations.

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Table 1. Analyzed nutrient composition of corn, wheat, sorghum, soybean meal (SBM), canola meal, high fat DDGS (HF-DDGS), low fat DDGS (LF-DDGS), corn germ meal (CGM), corn bran, wheat middlings (WM), and soybean hulls, as-fed basis

	Ingredient										
Item	Corn	Wheat	Sorghum	SBM	Canola meal	HF-DDGS	LF-DDGS	CGM	Corn bran	WM	Soybean hulls
GE, kcal/kg	3,990	3,858	3,850	4,272	4,259	4,782	4,378	4,195	4,281	4,109	3,640
DM, %	91.73	90.49	88.16	90.49	89.12	88.77	88.44	88.81	91.09	89.72	87.03
CP, %	9.17	12.73	10.01	50.33	35.83	29.34	33.28	21.95	10.25	16.13	9.97
AEE[1], %	3.96	1.86	4.33	0.43	2.42	12.2	7.99	3.73	4.09	5.18	1.14
Ash, %	1.17	1.61	1.20	6.17	7.84	4.64	6.17	3.05	0.89	5.81	4.36
Ca, %	0.01	0.04	0.01	0.33	1.01	0.03	0.04	0.02	0.01	0.10	0.54
P, %	0.23	0.32	0.26	0.68	1.07	0.84	0.97	0.75	0.12	1.20	0.10
Chloride, %	<0.10	<0.10	<0.10	<0.10	0.20	0.20	0.20	0.20	0.20	<0.10	<0.10
Mg, %	0.10	0.12	0.13	0.31	0.65	0.35	0.40	0.26	0.06	0.50	0.20
K, %	0.31	0.38	0.33	2.40	1.27	1.21	1.30	0.46	0.26	1.33	1.36
S, %	0.11	0.14	0.09	0.45	0.98	0.80	0.95	0.34	0.18	0.22	0.11
Na, (ppm)	8.00	<0.20	<0.20	55.0	219.0	1,025	2,332	166.00	38.00	34.00	5.00
Cu, (ppm)	6.00	10.00	6.00	34.00	21.00	14.00	14.00	17.00	6.00	29.00	11.00
Fe, (ppm)	62.00	72.00	56.00	154.00	268.00	163.00	145.00	219.00	166.00	225.00	459.00
Zn, (ppm)	36.00	26.00	18.00	45.00	65.00	79.00	75.00	93.00	21.00	105.00	31.00
Mn, (ppm)	6.00	52.00	16.00	32.00	87.00	16.00	17.00	14.00	4.00	147.00	12.00
Se, (ppm)	<4.00	<4.00	<4.00	<4.00	<4.00	<4.00	<4.00	<4.00	<4.00	<4.00	<4.00
Carbohydrates, %											
Glucose	0.44	0.39	0.36	1.34	0.68	0.27	0.37	0.19	0.46	1.74	0.31
Fructose	0.47	0.33	0.18	0.79	0.65	0.08	0.10	0.68	0.54	1.31	1.25
Sucrose	1.02	0.47	0.04	7.51	5.47	0.03	0.00	0.09	0.00	0.69	0.36
Maltose	0.15	0.11	0.06	0.45	0.00	0.67	0.33	0.03	0.02	0.32	0.07
Raffinose	0.05	0.14	0.01	0.50	0.27	0.00	0.00	0.00	0.00	0.55	0.05

Stachyose	0.00	0.00	0.00	1.32	0.38	0.00	0.00	0.00	0.00	0.00	0.07
Verbascose	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Starch, %	64.50	69.54	67.28	1.02	0.00	5.57	5.60	11.93	22.20	19.27	0.00
NDF, %	12.71	11.79	23.81	8.28	25.90	29.79	30.87	55.06	49.65	40.99	61.30
ADF, %	2.51	2.36	4.26	4.48	17.21	8.17	8.09	13.03	12.37	12.32	45.90
Lignin, %	0.62	0.78	0.58	0.31	6.45	0.74	0.75	2.44	0.97	3.73	1.85
Bulk density, g/L	748.7	1,030	1,049	773.5	776.8	712.6	562.4	642.5	256.8	447.0	588.0
WBC, g/g	1.29	1.15	1.11	2.93	3.18	1.94	1.94	3.67	3.13	4.06	5.05
Indispensable AA, %											
Arg	0.39	0.54	0.31	3.42	2.11	1.15	1.24	1.63	0.38	1.17	0.41
His	0.23	0.25	0.19	1.27	0.95	0.70	0.78	0.68	0.33	0.45	0.25
Ile	0.28	0.36	0.35	2.24	1.42	1.00	1.10	0.85	0.31	0.52	0.34
Leu	0.96	0.69	1.18	3.71	2.51	3.10	3.40	1.82	1.11	1.03	0.57
Lys	0.28	0.35	0.19	3.04	2.05	0.89	1.07	0.97	0.28	0.75	0.62
Met	0.18	0.17	0.14	0.64	0.70	0.51	0.58	0.42	0.15	0.24	0.09
Phe	0.39	0.45	0.45	2.43	1.39	1.29	1.41	1.05	0.45	0.63	0.34
Thr	0.28	0.31	0.27	1.79	1.49	1.00	1.08	0.85	0.37	0.53	0.31
Trp	0.06	0.13	0.05	0.62	0.44	0.18	0.18	0.16	0.06	0.16	0.06
Val	0.39	0.48	0.45	2.40	1.86	1.33	1.44	1.36	0.46	0.78	0.43
Dispensable AA, %											
Ala	0.59	0.39	0.81	2.04	1.54	1.82	2.07	1.43	0.63	0.79	0.38
Asp	0.53	0.54	0.56	5.28	2.51	1.62	1.89	1.68	0.51	1.18	0.79
Cys	0.17	0.23	0.13	0.63	0.82	0.49	0.56	0.31	0.20	0.30	0.14
Glu	1.42	2.62	1.71	8.14	5.63	3.62	4.42	3.00	1.55	2.77	0.92
Gly	0.31	0.44	0.28	1.99	1.74	1.01	1.12	1.27	0.39	0.88	0.82
Pro	0.68	0.88	0.70	2.37	2.11	2.01	2.36	1.15	0.96	0.98	0.45
Ser	0.38	0.46	0.38	2.05	1.30	1.18	1.35	0.90	0.40	0.66	0.45
Tyr	0.27	0.29	0.31	1.77	0.99	1.05	1.10	0.69	0.31	0.44	0.38
Total AA	7.79	9.58	8.46	45.83	31.56	23.95	27.15	20.22	8.85	14.26	7.75

[1]AEE= acid hydrolyzed either extract.

Table 2. Ingredient composition of experimental diets containing corn, wheat, sorghum, soybean meal (SBM), canola meal, conventional distillers dried grains with solubles (HF-DDGS), low-fat distiller dried grains with solubles (LF-DDGS), corn germ meal (CGM), corn bran, wheat middlings (WM), and soy hulls, as-fed basis

	Diet										
Item	Corn	Wheat	Sorghum	SBM	Canola meal	HF-DDGS	LF-DDGS	CGM	Corn bran	WM	Soybean hulls
Ingredients, %											
Corn	97.1	-	-	72.1	61.0	45.9	45.8	57.5	57.6	57.9	57.6
Wheat	-	97.7	-	-	-	-	-	-	-	-	-
Sorghum	-	-	97.1	-	-	-	-	-	-	-	-
SBM	-	-	-	25.5	-	-	-	-	-	-	-
Canola meal	-	-	-	-	37.0	-	-	-	-	-	-
HF-DDGS	-	-	-	-	-	52.0	-	-	-	-	-
LF-DDGS	-	-	-	-	-	-	52.0	-	-	-	-
Corn germ meal	-	-	-	-	-	-	-	40.0	-	-	-
Corn bran	-	-	-	-	-	-	-	-	40.0	-	-
Wheat middlings	-	-	-	-	-	-	-	-	-	40.0	-
Soybean hulls	-	-	-	-	-	-	-	-	-	-	40.0
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 P	1.25	0.36	1.10	0.80	0.80	-	0.15	0.55	1.25	-	1.35
Salt	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[1]	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

[1]Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D3 as cholecalciferol, 2,208 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B12, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

Table 3. Chemical composition of experimental diets containing corn, wheat, sorghum, soybean meal (SBM), canola meal, conventional distillers dried grains with solubles (HF-DDGS), low-fat distiller dried grains with solubles (LF-DDGS), corn germ meal (CGM), corn bran, wheat middlings (WM), and soy hulls, as-fed basis

	Diet										
Item	Corn	Wheat	Sorghum	SBM	Canola meal	HF-DDGS	LF-DDGS	CGM	Corn bran	WM	Soybean hulls
GE, kcal/kg	3764	3764	3760	3866	3888	4229	4090	3820	3904	3814	3728
DM, %	87.9	88.6	87.3	88.4	88.7	88.9	88.8	89.1	89.5	88.2	89.4
CP, %	9.61	13.2	8.46	20.0	19.3	18.7	19.6	18.3	8.56	11.6	9.14
AEE[1], %	1.78	1.59	1.81	2.15	2.49	7.61	4.93	1.84	3.39	3.72	4.37
Ash, %	3.61	3.71	3.99	4.79	6.11	5.15	5.30	3.74	2.81	4.31	4.40
Carbohydrates, %											
Glucose	-	-	-	0.48	-	-	-	-	-	-	0.48
Fructose	-	-	-	0.54	-	-	-	-	-	-	0.83
Sucrose	-	-	-	2.40	-	-	-	-	-	-	0.61
Maltose	-	-	-	0.12	-	-	-	-	-	-	0.11
Raffinose	-	-	-	0.16	-	-	-	-	-	-	0.05
Stachyose	-	-	-	0.26	-	-	-	-	-	-	0.03
Verbascose	-	-	-	0.00	-	-	-	-	-	-	0.00
NDF%	11.6	11.7	19.3	12.0	17.6	23.7	22.3	29.7	37.0	24.4	29.4
ADF%	3.07	2.39	4.04	3.31	7.97	5.27	5.53	6.40	7.93	5.42	18.1

[1]AEE= acid hydrolyzed ether extract.

Table 4. Comparative digestive utilization of corn, wheat, or sorghum diets in growing pigs and gestating sows[1]

	Corn		Wheat		Sorghum			*P*-value		
Item	Sows	Pigs	Sows	Pigs	Sows	Pigs	SEM	diet	Stage	diet*stage
ATTD of GE, %	88.23	85.84	90.85	89.26	88.88	85.94	1.09	<0.01	<0.01	0.70
ATTD of CP, %	84.96	66.98	91.97	85.67	73.30	61.85	3.20	<0.01	<0.01	0.14
ATTD of ADF, %	56.99[a]	53.66[a]	16.79[c]	30.72[b]	65.28[a]	64.58[a]	6.17	<0.01	0.55	<0.05
ATTD of NDF, %	76.24[b]	66.24[c]	66.16[c]	72.55[b]	89.38[a]	86.99[a]	2.14	<0.01	0.22	<0.01
DE, kcal/kg, as-fed basis	3,321	3,231	3,420	3,360	3,342	3,231	41	<0.01	<0.01	0.71
ME, kcal/kg, as-fed basis	3,223	3,037	3,296	3,212	3,278	3,093	51	<0.05	<0.01	0.33
DE, kcal/kg, DM basis	3,780	3,678	3,858	3,790	3,830	3,703	47	<0.05	<0.01	0.70
ME, kcal/kg, DM basis	3,669	3,457	3,718	3,623	3,757	3,545	58	<0.05	<0.01	0.33
ME/DE, %	85.26	82.45	85.42	84.60	84.58	83.37	1.18	0.40	0.07	0.54

[a-c]Least square means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are means of 8 observations.

Table 5. Comparative digestive utilization of diets containing soybean meal (SBM), canola meal (CM), conventional distillers dried grains with solubles (HF-DDGS), or low-fat distillers dried grains with solubles (LF-DDGS) in growing pigs and gestating sows[1]

	SBM		CM		HF-DDGS		LF-DDGS			*P*-value		
Item	Sows	Pigs	Sows	Pigs	Sows	Pigs	Sows	Pigs	SEM	diet	Stage	diet*stage
ATTD of GE, %	87.40	87.22	81.06	80.48	82.48	78.59	82.37	80.56	1.20	<0.01	<0.05	0.17
ATTD of CP, %	88.46	87.41	82.68	77.62	85.43	81.08	85.36	80.64	1.48	<0.01	<0.01	0.34
ATTD of ADF, %	50.44[bc]	59.57[a]	27.84[e]	34.60[de]	47.85[bc]	42.11[cd]	48.21[bc]	54.84[ab]	4.04	<0.01	0.08	<0.05
ATTD of NDF, %	76.07[a]	73.43[ab]	54.45[e]	61.34[d]	70.35[b]	59.48[de]	69.05[bc]	63.41[cd]	2.70	<0.01	0.07	<0.01
DE, kcal/kg, as-fed basis	3,341	3,365	3,151	3,122	3,488	3,317	3,369	3,288	51	<0.01	0.05	0.08
ME, kcal/kg, as-fed basis	3,165	3,203	2,950	2,969	3,279	3,143	3,164	3,202	71	<0.01	0.83	0.35
DE, kcal/kg, DM basis	3,779	3,807	3,554	3,522	3,924	3,732	3,796	3,705	57	<0.01	0.05	0.08
ME, kcal/kg, DM basis	3,581	3,624	3,328	3,349	3,689	3,536	3,565	3,607	80	<0.01	0.83	0.35
ME/DE, %	83.71	84.05	83.58	83.86	83.55	84.00	83.36	86.15	1.17	0.76	0.24	0.61

[a-e]Least square means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Data are means of 8 observations.

Table 6. Comparative digestive utilization of diets containing corn germ meal (CGM), corn bran, wheat millings (WM), or soybean hulls (SBH) in growing pigs and gestating sows[1]

	CGM		Corn bran		WM		SBH			*P*-value		
Item	Sows	Pigs	Sows	Pigs	Sows	Pigs	Sows	Pigs	SEM	diet	Stage	diet*stage
ATTD of GE, %	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
ATTD of CP, %	80.60	77.18	71.53	70.21	82.98	71.36	63.09	57.50	2.47	<0.01	<0.01	0.16
ATTD of ADF, %	61.72^{b}	75.38^{a}	55.49^{b}	60.47^{b}	34.18^{c}	34.66^{c}	79.48^{a}	53.51^{b}	3.26	<0.01	0.43	<0.01
ATTD of NDF, %	82.19^{a}	85.84^{a}	67.77^{bc}	72.41^{b}	65.66^{c}	66.70^{bc}	81.10^{a}	62.11^{c}	2.32	<0.01	0.15	<0.01
DE, kcal/kg, as-fed basis	3,160^{a}	3,206^{a}	3,102^{ab}	3,092^{ab}	3,208^{a}	3,010^{b}	3,010^{b}	2,825^{c}	58	<0.01	<0.05	<0.05
ME, kcal/kg, as-fed basis	3,009^{ab}	3,086^{a}	3,000^{abc}	2,947^{abc}	3,094^{a}	2,850^{cd}	2,924^{bc}	2,703^{d}	61	<0.01	<0.05	<0.05
DE, kcal/kg, DM basis	3,548^{abc}	3,600^{ab}	3,466^{bcd}	3,455^{bcd}	3,637^{a}	3,411^{cd}	3,369^{d}	3,161^{e}	65	<0.01	<0.05	<0.05
ME, kcal/kg, DM basis	3,379^{ab}	3,465^{a}	3,352^{ab}	3,293^{b}	3,507^{a}	3,230^{b}	3,272^{b}	3,026^{c}	69	<0.01	<0.05	<0.05
ME/DE, %	80.60	77.18	71.53	70.21	82.98	71.36	63.09	57.50	2.51	<0.01	<0.01	0.16

[a-d]Least square means within a row lacking a common superscript letter are different (*P* < 0.05).

[1]Data are means of 8 observations.

Table 7. Prediction of apparent total tract digestibility of energy and nutrients, and DE and ME of diets for gestating sows from values in growing pigs[1]

Item[2]	Equation	R^2	*P*-value
ATTD of GE, %	$22.7553 + 0.7506*ATTDGE_{pig}$	0.78	<0.001
ATTD of CP, %	$27.2137 + 0.7232*ATTDCP_{pig}$	0.72	<0.001
ATTD of ADF, %	$-2.8492 + 1.0192*ATTDADF_{pig}$	0.55	<0.01
ATTD of NDF, %	$28.4391 + 0.6276*ATTDNDF_{pig}$	0.36	0.05
DE, kcal/kg DM	$911.57 + 0.7727*DE_{pig}$	0.78	<0.001
ME, kcal/kg DM	$1267.29 + 0.6587*ME_{pig}$	0.54	<0.01

[1]A total of 11 diets were used.

[2]ATTD = apparent total tract digestibility.

Table 8. Correlation coefficients (r) between chemical components and digestibility of energy and nutrients and DE and ME in 11 diets fed to growing pigs or gestating sows, DM basis[1]

	Correlation coefficient, r					
Item[2]	GE Kcal/kg	CP g/kg	AEE g/kg	Ash g/kg	ADF g/kg	NDF g/kg
Sows						
ATTD of GE, %	-0.27	-0.14	-0.53	-0.21	-0.80**	-0.67*
ATTD of CP, %	0.37	0.60	-0.10	0.27	-0.69*	-0.81**
ATTD of ADF, %	-0.18	-0.35	0.11	-0.28	0.45	0.53
ATTD of NDF, %	-0.29	-0.35	-0.18	-0.41	0.09	0.10
DE, kcal/kg DM	0.52	0.29	0.12	0.18	-0.66*	-0.80**
ME, kcal/kg DM	0.28	-0.03	-0.02	-0.08	-0.62*	-0.76**
Growing pigs						
ATTD of GE, %	-0.24	0.10	-0.69*	-0.22	-0.75**	-0.76**
ATTD of CP, %	0.47	0.79**	0.05	0.32	-0.39	-0.58
ATTD of ADF, %	-0.09	-	-0.19	-0.34	0.41	0.12
ATTD of NDF, %	-0.39	-0.14	-0.66*	-0.48	0.01	-0.35
DE, kcal/kg DM	0.42	0.47	-0.15	0.12	-0.67*	-0.88**
ME, kcal/kg DM	0.42	0.50	-0.17	0.15	-0.61*	-0.84**

*$P < 0.05$, **$P < 0.01$.

[1]A total of 11 diets were used.

[2]AEE =acid-hydrolyzed ether extract; ATTD = apparent total tract digestibility.

Table 9. Effects of diet composition (g/kg of DM) on digestibility of energy and nutrients and the concentration of DE and ME (kcal/kg, DM) in growing pigs and gestating sows[1]

			Parameter estimate											
Item	Stage	Intercept	GE, kcal/kg	CP, g/kg	AEE,[3] g/kg	Ash, g/kg	ADF, g/kg	NDF, g/kg	C(p)	R^2	AIC	RMSE	*P*-value
ATTD of GE, %	Sow	97.53	-	-0.0248	-0.0192	-	-0.0264	-0.0282	4.75	0.85	17.43	1.90	<0.05
ATTD of GE, %	Pig	101.34	-	0.0353	-0.0563	-0.2833	-0.0364	-	5.03	0.93	13.15	1.56	<0.01
ATTD of CP, %	Sow	286.00	-0.0503	0.1051	0.3434	-	-	-0.2018	4.71	0.91	29.93	3.35	<0.01
ATTD of CP, %	Pig	158.91	-0.0209	0.1886	0.2043	-0.4122	-0.0211	-0.0775	7.00	0.85	42.05	5.93	<0.05
ATTD of ADF, %	Sow	-507.11	0.1445	-0.0557	-0.7759	-1.1915	-0.0636	0.5078	7.00	0.50	68.65	19.88	0.69
ATTD of ADF, %	Pig	-473.17	0.1322	0.0676	-1.0023	-1.0632	0.0092	0.3120	7.00	0.60	59.23	12.96	0.53
ATTD of NDF, %	Sow	-20.04	0.0300	-0.0046	-0.1650	-0.6287	-0.0385	0.1208	7.00	0.23	59.96	13.40	0.96
ATTD of NDF, %	Pig	52.70	0.0057	0.0152	-0.3624	-0.0837	0.0518	-0.0678	7.00	0.66	50.00	8.52	0.42
DE, kcal/kg DM	Sow	2750.28	0.3294	-0.4031	2.9577	-2.7199	-1.1788	-1.7808	7.00	0.91	100.66	85.17	<0.01
DE, kcal/kg DM	Pig	-859.82	1.2275	0.9246	-5.3221	-10.8080	-1.4293	0.1322	7.00	0.96	95.26	66.64	<0.01
ME, kcal/kg DM	Sow	3360.92	0.1884	-1.1757	3.2946	-3.3369	-1.1621	-1.9782	7.00	0.85	105.48	106.04	<0.05
ME, kcal/kg DM	Pig	-1739.9	1.3693	0.8217	-7.3042	-8.9457	-1.1202	0.4537	7.00	0.90	104.28	100.45	<0.01

[1]Candidate models are those where C(p) is similar to p. P is the number of variables in the model +1. The optimal model is the prediction equation with the lowest AIC (measure of fit) and root mean square error (RMSE; measure of precision).