Published October 24, 2016

Effects of tallow, choice white grease, palm oil, corn oil, or soybean oil on apparent total tract digestibility of minerals in diets fed to growing pigs[1]

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ABSTRACT: An experiment was conducted to determine the effect of supplementing diets fed to growing pigs with fat sources differing in their composition of fatty acids on the apparent total tract digestibility (ATTD) of minerals. A diet based on corn, potato protein isolate, and 7% sucrose was formulated. Five additional diets that were similar to the previous diet with the exception that sucrose was replaced by 7% tallow, choice white grease, palm oil, corn oil, or soybean oil were also formulated. Diets were formulated to contain 0.70% Ca and 0.33% standardized total tract digestible P. Growing barrows (n = 60; 15.99 ± 1.48 kg initial BW) were allotted to a randomized complete block design with 2 blocks of 30 pigs, 6 dietary treatments, and 10 replicate pigs per treatment. Experimental diets were provided for 12 d with the initial 5 d being the adaptation period. Total feces were collected for a 5-d collection period using the marker-to-marker approach, and the ATTD of minerals, ether extract, and acid hydrolyzed ether extract was calculated for all diets. Digestibility of DM was greater ($P < 0.05$) in the diet containing soybean oil compared with the diet containing choice white grease or the basal diet, with all other diets being intermediate. The ATTD of Ca, S, and P was greater ($P < 0.05$) for pigs fed diets containing soybean oil, corn oil, palm oil, or tallow than for pigs fed the basal diet or the diet containing choice white grease. The ATTD of Mg, Zn, Mn, Na, and K were not different among dietary treatments. The ATTD of ether extract was greater ($P < 0.05$) in diets containing palm oil, corn oil, or soybean oil compared with the diet containing choice white grease, and the ATTD of acid hydrolyzed ether extract in the diet containing soybean oil was also greater ($P < 0.05$) than in the diet containing choice white grease. In conclusion, supplementation of a basal diet with tallow, palm oil, corn oil, or soybean oil may increase the ATTD of some macrominerals, but that appears not to be the case if choice white grease is used. There was no evidence of negative effects of the fat sources used in this experiment on the ATTD of any minerals.

Key words: calcium digestibility, choice white grease, fat, minerals, pigs, plant oil

 J. Anim. Sci. 2016.94:4231–4238
doi:10.2527/jas2016-0682

INTRODUCTION

Supplementation of soybean oil to diets fed to pigs does not influence the digestibility of Ca and P (Steiner et al., 2006; González-Vega et al., 2015). In contrast, in humans, increasing dietary Ca intake reduces the digestibility of fat (Bendsen et al., 2008), and elevated levels of dietary Ca and vitamin D may increase the loss of energy by fecal excretion of indigestible complexes between Ca and fat (Soares et al., 2012). It is possible that the reason for this apparent discrepancy is that more saturated fat sources have been used in the experiments with humans than in the pig experiments.

Sources of fat vary in the relative concentrations of SFA, MUFA, and PUFA (Boyle and Long, 2006). Oil extracted from corn and soybeans have low concentrations of saturated fats (13 to 15% of total fatty acids) and greater concentrations of MUFA (24 to 25% of total fatty acids) and PUFA (61 to 62%; Boyle and Long, 2006). In contrast, beef tallow and palm oil contain more SFA (51 to 52% of total fatty acids) and more MUFA (39 to 44% of total fatty acids) but less PUFA (4 to 10%; Boyle and Long, 2006).

[1]Financial support for this research from AB Vista Feed Ingredients, Marlborough, UK, is appreciated.

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Received May 28, 2016.
Accepted August 8, 2016.

To our knowledge, no experiments have been conducted to evaluate the impact of different sources of dietary fat on the digestibility of Ca and other minerals by pigs; however, based on previous research with pigs and humans, we hypothesized that fats with greater concentrations of SFA may have a greater negative impact on Ca digestibility than more unsaturated fatty acids. Therefore, the objective of this experiment was to test the hypothesis that the apparent total tract digestibility (**ATTD**) of Ca and other minerals is influenced by the source of fat that is included in the diet.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocol for the experiment. Pigs used in the experiment were the offspring of Line 359 boars and C-46 females (PIC, Hendersonville, TN).

Animals and Housing

Sixty barrows were weaned at approximately 21 d of age and fed a phase 1 diet based on corn, soybean meal, spray dried protein plasma, fish meal, and whey powder for 2 wk and a phase 2 diet based on corn, soybean meal, and whey powder for 2 wk. Pigs were then randomly allotted to 6 diets with 10 replicate pigs per treatment. Pigs had an average initial BW of 15.99 ± 1.48 kg at the start of the experiment and were approximately 7 wk of age. There were 2 blocks of 30 pigs with 5 replicate pigs in each block. Pigs were individually housed in stainless steel metabolism crates (0.50 by 0.50 m) that were equipped with a slatted floor, a stainless steel feeder, a nipple drinker, and a screen floor, which allowed for total fecal collection. The Experimental Animal Allotment Program (Kim and Lindemann, 2007) was used to allot pigs to experimental diets.

Diets and Feeding

Soybean oil and choice white grease were obtained from the University of Illinois Feed Mill (Champaign, IL), and tallow, palm oil, and corn oil were purchased from Soapers Choice (Des Plaines, IL; Table 1). A basal diet based on corn and potato protein isolate that included 7% sucrose was formulated. Five additional diets were formulated by adding 7% tallow, choice white grease, palm oil, corn oil, or soybean oil to the basal diet at the expense of sucrose (Tables 2 and 3). All diets were formulated to meet or exceed requirements for AA, Ca, and P (NRC, 2012). Diets were formulated to contain 0.70% Ca and 0.33% standardized total tract digestible P. Corn, potato protein isolate, and monosodium phosphate contain no Ca or very limited quantities of Ca, and it was therefore possible to formulate diets in which practically all Ca was provided by calcium carbonate (ILC Resources, Alden, IA). Potato protein isolate contains approximately 81% CP, 0.10% ether extract, and 0.13% P (González-Vega et al., 2015).

Pigs were fed their respective diet for 12 d, and they were provided feed at a level equal to 3 times the daily maintenance energy requirement (i.e., 197 kcal of ME/kg $BW^{0.60}$; NRC, 2012). The daily allotment of feed was divided into 2 equal meals and provided at 0700 and 1600 h. Pigs were provided free access to water throughout the experiment. The initial 5 d was the adaptation period to the diet, and fecal samples were quantitatively collected from d 6 to 12 using the marker-to-marker approach (Adeola, 2001). On d 6, 2 g of a color marker (indigo carmine) was added to the morning meal to mark the beginning of fecal collection, and on d 11, 2 g of the second marker (ferric oxide) was added to the morning meal to mark the conclusion of fecal collection. Fecal samples were stored at −20°C immediately after collection. The orts collected were dried in a forced-air oven at 65°C, and the weight was subtracted from the total feed intake.

Sample Analyses. Diets and orts were analyzed for DM using a drying oven at 135°C for 2 h (method 930.15; AOAC Int., 2007), and diets were analyzed for ash (method 942.05; AOAC Int., 2007). Diets were also analyzed for N using the combustion procedure (method 990.03; AOAC Int., 2007) on an Elementar Rapid N-cube protein/nitrogen apparatus (Elementar Americas Inc., Mt. Laurel, NJ), and CP was calculated as N × 6.25. Aspartic acid was used as the internal standard. Diets were also analyzed for ADF (method 973.18; AOAC Int., 2007) and NDF (Holst, 1973). Minerals were analyzed in diets by inductively coupled plasma spectroscopy (method 985.01 A, B, and C; AOAC Int., 2007) after wet ash sample preparation (method 975.03 B(b); AOAC Int., 2007). Diets were also analyzed for GE using bomb calorimetry (model 6300; Parr Instruments, Moline, IL) with benzoic acid being the internal standard and for acid hydrolyzed ether extract using an ANKOM HCL hydrolysis system and an ANKOM XT15 fat extractor (Ankom Technologies, Macedon, NY; method AM 5-04; AOAC Int., 2007). Ether extract without acid hydrolysis was analyzed the same way as acid hydrolyzed ether extract except that the acid hydrolysis step was not performed.

The 5 sources of fat were analyzed at Experiment Station Chemical Laboratories, University of Missouri, Columbus, MO, for ether extract (method 996.06; AOAC Int., 2007), insolubles (method CA 3a-46; AOAC Int., 2007), unsaponifiables (method Ca 6a-40; AOAC Int., 2007), moisture (method Ca 2c-25;

Table 1. Analyzed composition of fat sources[1]

Item, %	Ingredient				
	Tallow	Choice white grease	Palm oil	Corn oil	Soybean oil
Ether extract	86.58	98.99	96.25	99.83	97.21
Moisture	0.98	0.93	1.60	0.53	2.89
Insolubles	0.15	0.76	0.23	0.08	0.09
Unsaponifiables	0.27	0.61	0.24	0.77	0.51
Total fatty acids	85.79	92.39	92.82	94.31	94.09
Free fatty acids	0.36	13.98	0.38	0.21	0.22
Peroxide value	2.53	45.25	11.29	5.51	24.75
Fatty acid profile, expressed as percent of total fat					
Myristic acid (14:0)	3.12	1.53	0.90	0.04	0.08
Myristoleic acid (9*c*-14:1)	0.69	0.12	0.00	0.00	0.00
C15:0	0.51	0.13	0.06	0.01	0.02
Palmitic acid (16:0)	23.51	23.09	41.51	11.67	10.90
Palmitoleic acid (9*c*-16:1)	2.69	2.21	0.15	0.11	0.09
Margaric acid (17:0)	1.44	0.50	0.12	0.07	0.10
Stearic acid (18:0)	15.19	13.29	4.36	1.80	4.60
Oleic acid (9*c*-18:1)	35.32	36.77	41.90	27.76	22.38
Vaccenic acid (11*c*-18:1)	1.34	2.51	0.69	0.59	1.42
Linoleic acid (18:2*n*-6)	3.00	12.24	8.21	54.82	50.70
Linolenic acid (18:3*n*-3)	0.21	0.51	0.16	0.91	6.65
Arachidic acid (20:0)	0.12	0.22	0.39	0.41	0.38
Gonodic acid (20:1*n*-9)	0.25	0.88	0.17	0.26	0.21
Behenoic acid (22:0)	0.02	0.04	0.07	0.14	0.38
Erucic acid (22:1*n*-9)	0.00	0.05	0.00	0.00	0.00
Lignoceric acid (24:0)	0.00	0.03	0.08	0.17	0.14

[1]Nervonic acid (24:1*n*-9), docosahexaenoic acid (22:6*n*-3), clupanodonic acid (22:5*n*-3), eicosapentaenoic acid (20:5*n*-3), 3*n*-arachidonic acid (20:4*n*-3), arachidonic acid (20:4*n*-6), homo-a-linolenic acid (20:3*n*-3), stearidonic acid (18:4*n*-3), and elaidic acid (9*t*-18:1) were also analyzed but not detected in the samples.

AOAC Int., 2007), free fatty acids (method Ca 5a-40; AOAC Int., 2007), peroxide value (method 965.33, AOAC Int., 2007), and total fatty acid profile (method 966.06, AOAC Int., 2007).

Fecal samples were dried in a forced-air oven at 65°C and ground through a 1-mm screen using a Wiley mill (model 4; Thomas Scientific, Swedesboro, NJ). Fecal samples were analyzed for DM, minerals, acid hydrolyzed ether extract, and ether extract as explained for diets.

Calculations and Statistical Analyses. The ATTD values for DM, Ca, P, Mg, K, Na, S, Zn, Mn, ether extract, and acid hydrolyzed ether extract were calculated according to standard procedures (Almeida and Stein, 2010; NRC, 2012) using the direct method. Data were analyzed as a randomized complete block design using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). This model contained diet as a fixed effect and block as a random effect. To test for normality and to identify outliers, the UNIVARIATE procedure of SAS was used. The experimental unit for all analyses was the pig. The LSMeans procedure was used to calculate means, and significantly different means were separated using the pDiff option in SAS with the Tukey adjustment. Statistical significance was observed when $P < 0.05$ and tendencies were considered at $0.05 \leq P < 0.10$.

RESULTS

The ether extract in the fat sources was between 86.58 and 99.83% (Table 1), and moisture was between 0.53 and 2.89%. The insoluble fat was between 0.08 and 0.76% and unsaponifiables were between 0.27 and 0.77 in fat sources. Total fatty acids were between 85.79 and 94.09%, and free fatty acids were between 0.21 and 11.29%. The peroxide value of the fat sources was between 5.51 and 45.25.

Palmitic acid concentration was 23.51, 23.09, and 41.51% of total fats in tallow, choice white grease, and palm oil, respectively, but only 11.67 and 10.90% in corn oil and soybean oil, respectively. Linoleic acid was 3.00, 12.24, and 8.21% of total fats in tallow, choice white grease, and palm oil, respectively, but 54.82 and 50.70% in corn and soybean oil, respectively.

Digestibility of DM was greater ($P < 0.05$) for pigs fed the diet containing soybean oil than for pigs fed the diet containing choice white grease or the basal diet, with pigs fed all remaining diets being intermediate (Table 4). The ATTD of Ca, P, and S were greater ($P < 0.05$) for pigs fed diets containing soybean oil, corn oil, palm oil, or tallow than for pigs fed the basal diet or the diet with choice white grease. There was a tendency

Table 2. Ingredient composition of experimental diets, as-fed basis

		Source of fat				
Ingredient, %	Basal	Tallow	Choice white grease	Palm oil	Soybean oil	Corn oil
Corn	71.59	71.59	71.59	71.59	71.59	71.59
Potato protein isolate	18.00	18.00	18.00	18.00	18.00	18.00
Sucrose	7.00	–	–	–	–	–
Source of fat	–	7.00	7.00	7.00	7.00	7.00
Calcium carbonate	1.73	1.73	1.73	1.73	1.73	1.73
Monosodium phosphate	0.98	0.98	0.98	0.98	0.98	0.98
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40
L-Lys HCl, 78% Lys	0.10	0.10	0.10	0.10	0.10	0.10
Vitamin–mineral premix[1]	0.20	0.20	0.20	0.20	0.20	0.20
Total	100.00	100.00	100.00	100.00	100.00	100.00

[1]The vitamin–micromineral premix provide the following quantities of vitamins and microminerals per kilogram of complete diet: 11,136 IU vitamin A as retinyl acetate, 2,208 IU vitamin D_3 as cholecalciferol, 66 IU vitamin E as DL-alpha tocopheryl acetate, 1.42 mg vitamin K as menadione dimethylprimidinol bisulfite, 0.24 mg thiamin as thiamine mononitrate, 6.59 mg riboflavin, 0.24 mg pyridoxine as pyridoxine hydrochloride, 0.03 mg vitamin B_{12}, 23.5 mg D-pantothenic acid as D-calcium pantothenate, 44.1 mg niacin, 1.59 mg folic acid, 0.44 mg biotin, 20 mg Cu as copper sulfate, 126 mg Fe as iron sulfate, 1.26 mg I as ethylenediamine dihydriodide, 60.2 mg Mn as manganous sulfate, 0.25 mg Se as sodium selenite and selenium yeast, and 124.9 mg Zn as zinc sulfate.

($P = 0.057$) for the ATTD of Mg to be greater in pigs fed diets containing soybean oil or corn oil compared with pigs fed diets containing tallow or choice white grease. The ATTD of K, Mn, Na, and Zn was not different among dietary treatments (Tables 4 and 5).

The ATTD of ether extract was greater ($P < 0.01$) in diets containing soybean oil, corn oil, or palm oil than in the diet containing choice white grease but not different from the diet containing tallow (Table 6). The ATTD of ether extract in the basal diet was less than in all other diets ($P < 0.01$). The ATTD of acid hydrolyzed ether extract was greater ($P < 0.01$) in the diet containing soybean oil than in the diet containing choice white grease with diets containing tallow, palm oil, or corn oil being intermediate, but the ATTD of acid hydrolyzed ether extract in the basal diet was less ($P < 0.01$) than in all other diets. Regardless of fat analysis method, fecal fat was greater ($P < 0.01$) in diets containing choice white grease or palm oil than in diets containing soybean oil or corn oil, with tallow and the basal diet being intermediate.

DISCUSSION

Concentrations of C16:0, C18:0, C18:1, and C18:2 fatty acids in tallow, choice white grease, palm oil, corn oil, and soybean oil were consistent with values previously reported (Cera et al., 1988; Li et al., 1990; Cater et al., 1997), with greater concentrations of SFA in tallow, choice white grease, and palm oil and greater concentrations of unsaturated fatty acids in corn oil and soybean oil. The fat sources used in this experiment also had different combinations of individual fatty acids, and if differences in fatty acid composition modified the digestibility of minerals or fat, we expected to be able to detect these differences.

The ATTD of Ca in these diets reflected the ATTD of Ca in calcium carbonate because calcium carbonate was the only source of Ca in the diets. The ATTD of Ca in all diets is in agreement with previous values reported for calcium carbonate (Stein et al., 2011; González-Vega et al., 2015; Merriman and Stein, 2016).

With the exception of choice white grease, the ATTD of Ca was not negatively influenced by fat. This indicates that complexes between Ca and fat in the gastrointestinal tract did not result in a reduction in the digestibility of fat or Ca and it is therefore not likely that Ca influences the digestibility of energy. In the current experiment, fat was analyzed both as ether extract and as acid hydrolyzed ether extract. The acid hydrolysis step breaks the bonds between fat and Ca, and a better estimation of fat content is expected (Stoldt, 1952). Because it has been suggested that soaps between Ca and fat are excreted in the feces, samples were subjected to both methods of analysis to determine if such Ca–fat complexes could be quantified. However, the values for ATTD of acid hydrolyzed ether extract and ether extract were almost identical, further indicating that complexes between Ca and fat were not excreted in the feces. These results are also in agreement with observations indicating that there is no influence on the digestibility of Ca by addition of fat to conventional diets fed to pigs (Steiner et al., 2006; González-Vega et al., 2015). However, data from humans have indicated that increasing the concentrations of dietary Ca may result in formation of insoluble complexes between Ca and fat, leading to excretion of Ca and fat in the feces, which may result in weight loss (Davies et al., 2000; Zemel et al., 2000; 2002; Zemel, 2001; Heaney, 2003; Lorenzen et al., 2007; Bendsen et al., 2008). However, results have been inconclusive, and some data indicate that only Ca in dairy products, not Ca from inorganic supplements, results in formation of Ca–fat complexes (Lorenzen et

Table 3. Analyzed composition of experimental diets, as-fed basis[1,2]

	Diet					
Ingredient	Basal	Tallow	Choice white grease	Palm oil	Corn oil	Soybean oil
DM, %	88.14	89.62	89.41	89.44	88.03	89.62
Ash, %	4.40	4.01	4.57	4.43	4.42	4.28
GE, %	3,940	4,275	4,360	4,457	4,460	3,798
CP, %	20.87	20.80	22.41	19.94	21.48	21.13
AEE,[3] %	2.37	9.66	8.97	9.48	8.94	9.03
Ether extract, %	1.95	8.96	8.21	9.20	9.12	9.27
NDF, %	7.87	7.55	8.21	7.73	8.20	7.82
ADF, %	5.09	5.37	4.56	4.57	4.65	4.51
Ca, %	0.87	0.80	0.85	0.76	0.78	0.77
P, %	0.50	0.47	0.50	0.50	0.51	0.49
Na, %	0.37	0.40	0.37	0.36	0.41	0.38
K, %	0.25	0.22	0.26	0.25	0.24	0.25
S, %	0.28	0.30	0.30	0.28	0.30	0.28
Mg, mg/kg	662	574	693	686	659	658
Zn, mg/kg	79	100	143	83	93	128
Fe, mg/kg	174	163	154	163	162	162
Cu, mg/kg	13	12	17	25	10	12
Mn, mg/kg	69	84	59	60	52	31

[1]All diets were formulated to contain 1.40% Lys, 0.45% Met, 1.06% Thr, and 0.25% Trp.

[2]The basal diet was formulated to contain 3,399 kcal ME/kg; the diets containing tallow, palm oil, choice white grease, corn oil, and soybean oil were formulated to contain 3,695, 3,715, 3,585, 3,747, and 3,747 kcal ME/kg (as-fed basis), respectively.

[3]AEE = acid hydrolyzed ether extract.

Table 4. Apparent total tract digestibility (ATTD) of DM and macrominerals in diets containing different fat sources[1]

	Diet							
Item	Basal	Tallow	CWG[2]	Palm oil	Corn oil	Soybean oil	SEM	*P*-value
Intake, g/d	783[a]	644[c]	655[bc]	751[ab]	643[c]	680[bc]	38	0.023
Fecal output g DM/d	70[a]	54[bc]	63[ab]	62[abc]	53[bc]	51[c]	4	0.017
ATTD of DM, %	89.79[bc]	90.68[ab]	89.25[c]	90.88[ab]	90.73[ab]	91.59[a]	0.49	0.006
Ca intake, g/d	6.82[a]	5.15[b]	5.37[b]	5.70[b]	5.02[b]	5.24[b]	0.30	<0.001
Ca output, g/d	3.10[a]	1.84[c]	2.43[b]	2.04[bc]	1.72[c]	1.55[c]	0.22	<0.001
ATTD of Ca, %	51.65[b]	65.13[a]	54.07[b]	66.07[a]	67.47[a]	71.71[a]	3.00	<0.001
P intake, g/d	3.92[a]	3.22[c]	3.28[bc]	3.75[ab]	3.22[c]	3.4[bc]	0.19	0.023
P output, g/d	1.86[a]	1.21[c]	1.53[b]	1.46[bc]	1.30[bc]	1.26[c]	0.10	<0.001
ATTD of P, %	52.06[b]	62.00[a]	53.52[b]	61.06[a]	59.80[a]	62.98[a]	2.10	0.001
Mg intake, g/d	5.09[a]	4.18[c]	4.26[bc]	4.88[ab]	4.18[c]	4.42[bc]	2.46	0.023
Mg output, g/d	3.78[a]	3.07[bc]	3.47[ab]	3.57[ab]	2.90[c]	2.82[c]	2.19	0.004
ATTD of Mg, %	25.62	24.73	23.53	26.94	30.91	35.37	3.44	0.057
Na intake, g/d	3.13[a]	2.57[c]	2.62[bc]	3.00[ab]	2.57[c]	2.72[bc]	0.15	0.023
Na output, g/d	0.30[a]	0.24[bc]	0.24[abc]	0.28[ab]	0.23[bc]	0.22[c]	0.02	0.049
ATTD of Na, %	90.40	90.99	90.66	90.69	91.30	91.95	0.53	0.346
S intake, g/d	2.35[a]	1.93[c]	1.97[bc]	2.25[ab]	1.93[c]	2.04[bc]	0.11	0.023
S output, g/d	0.43[a]	0.32[b]	0.37[ab]	0.36[ab]	0.31[b]	0.32[b]	0.02	0.005
ATTD of S, %	81.70[b]	83.75[a]	81.31[b]	83.98[a]	84.03[a]	83.40[a]	0.73	0.011
K intake, g/d	1.96[a]	1.61[c]	1.64[bc]	1.88[ab]	1.61[c]	1.70[bc]	0.09	0.023
K output, g/d	0.44	0.41	0.45	0.43	0.42	0.35	0.04	0.419
ATTD of K, %	76.68	74.25	72.60	77.37	73.89	79.17	1.81	0.116

[a–c]Values within a row sharing a common superscript are not statistically different ($P < 0.05$).

[1]Data represent means of 10 observations per treatment.

[2]CWG = choice white grease.

Table 5. Apparent total tract digestibility (ATTD) of microminerals in diets containing different fat sources[1]

Item	Diet						SEM	*P*-value
	Basal	Tallow	CWG[2]	Palm oil	Corn oil	Soybean oil		
Mn intake, mg/kg	470.02^{a}	386.16^{c}	393.15^{bc}	450.43^{ab}	386.06^{c}	408.13^{bc}	22.67	0.023
Mn output, mg/kg	399.86^{a}	308.32^{b}	350.71^{ab}	354.91^{ab}	301.23^{b}	328.94^{b}	24.61	0.024
ATTD of Mn, %	14.70	20.59	10.96	21.43	22.49	19.38	4.14	0.206
Zn intake, mg/kg	783.34^{a}	843.60^{c}	655.25^{bc}	750.71^{ab}	643.43^{c}	680.21^{bc}	37.78	0.023
Zn output, mg/kg	670.82	566.99	621.38	647.67	532.39	592.82	43.99	0.158
ATTD of Zn, %	13.51	11.14	11.74	13.68	17.00	12.29	4.94	0.618

[a–c]Values within a row sharing a common superscript are not statistically different ($P < 0.05$).

[1]Data represent means of 10 observations per treatment.

[2]CWG = choice white grease.

al., 2007). Greater concentrations of Ca in the feces have also been observed at greater inclusion levels of dietary Ca (Bendsen et al., 2008), but it is not known if this greater excretion of Ca is a consequence of formation of Ca–fat complexes or if it is only a result of increased dietary Ca. Humans also tend to have intake of fat that may vary from day to day, whereas pigs in this experiment were fed the same diet every day, which may also influence the results.

The ATTD of minerals varied among the different minerals. The ATTD of Na and S was relatively high, which is consistent with previous values (Sauer et al., 2009; Song et al., 2013). The ATTD of Mg, Zn, and Mn was much lower than that of other minerals, but values were generally in agreement with previous reports (Kemme et al., 1999; Liu et al., 2014b). The ATTD of K was only slightly greater than values previously reported (Sauer et al., 2009).

The observation that the ATTD of Ca, P, S, ether extract, and acid hydrolyzed ether extract was less in the diet containing choice white grease compared with diets containing corn oil or soybean oil may be a result of a reduced quality of the fat in choice white grease. The peroxide value for choice white grease was more than 40 mEq/kg, and it has been indicated that growth performance of pigs is reduced if peroxide values exceed 40 mEq/kg (DeRouchey et al., 2004). The peroxide value is an estimate of the concentration of hydroperoxides and provides an estimate of the quality of the fat (DeRouchey et al., 2004). Previous results have demonstrated a reduction in growth performance as a result of lipid oxidation with choice white grease included at 6% of the diet (DeRouchey et al., 2004). Choice white grease also had greater concentrations of free fatty acids than the other fat sources, which further indicates that the choice white grease that was used in this experiment may have been oxidized. It is therefore likely that it is the quality of the choice white grease and not necessarily the type of fat that caused the negative effects on the ATTD of nutrients, although lipid oxidation does not always reduce ATTD of nutrients and energy (Liu et al., 2014a).

Pigs fed the basal diet had greater feed intake than pigs fed fat-supplemented diets, which is consistent with previous observations (DeRouchey et al., 2004). This was expected because the caloric density of the basal diet was less than that of the fat-supplemented diets and pigs were limit fed at 3 times the maintenance energy requirement. A reduction of feed from the fat-supplemented diets was therefore caused by the greater concentration of ME in the diets containing fat compared with the basal diet.

The low digestibility of fat in the basal diet is consistent with data indicating that a low digestibility

Table 6. Apparent total tract digestibility (ATTD) of ether extract (EE) and acid hydrolyzed ether extract (AEE) in diets containing different fat sources[1]

Item	Diet						SEM	*P*-value
	Basal	Tallow	CWG[2]	Palm oil	Corn oil	Soybean oil		
EE intake, g/d	15.28^{d}	57.67^{bc}	53.80^{c}	69.07^{a}	58.68^{bc}	63.06^{ab}	3.12	<0.001
EE output, g/d	10.59^{ab}	10.42^{abc}	11.97^{a}	11.49^{a}	9.02^{bc}	8.64^{c}	0.77	0.020
ATTD of EE, %	29.62^{c}	81.59^{ab}	77.77^{b}	83.23^{a}	84.59^{a}	86.15^{a}	2.02	<0.001
AEE intake, g/d	18.57^{c}	62.17^{b}	58.78^{b}	71.17^{a}	57.52^{b}	61.42^{b}	3.23	<0.001
AEE output, g/d	11.02^{abc}	11.68^{ab}	12.27^{a}	12.16^{a}	9.79^{bc}	9.04^{c}	0.80	0.011
ATTD of AEE, %	39.75^{c}	81.17^{ab}	79.05^{b}	82.77^{ab}	82.84^{ab}	85.17^{a}	1.67	<0.001

[a–c]Values within a row sharing a common superscript are not statistically different ($P < 0.05$).

[1]Data represent means of 10 observations per treatment.

[2]CWG = choice white grease.

in fat is observed in diets with low concentration of dietary fat because of the relatively high contribution of endogenous fat to the total output of fat (Kil et al., 2010). In addition, intact fat from plant ingredients has lower ATTD than extracted, supplemented fat (Kil et al., 2010). However, the ATTD of fat in the diets containing supplemented fat is consistent with results from previous experiments indicating that the ATTD of fat was 89% for corn oil, 84% for choice white grease, and 82% for tallow by pigs (Cera et al., 1988).

In conclusion, results of this experiment failed to support the hypothesis that fat will bind Ca in the intestinal tract and thereby reduce the digestibility of both fat and Ca. Under the conditions of this experiment, the degree of saturation of the dietary fat did not affect the digestibility of Ca. However, in the case of choice white grease, the quality of the fat or concentration of free fatty acids may reduce the ATTD of Ca, and this observation warrants further investigation. Regardless, the implication of this observation is that there is no need to reduce the inclusion of fat in diets for pigs to avoid creating a reduction in digestibility of Ca. Likewise, it appears that the energetic contribution of fat is not reduced by the inclusion of calcium carbonate in diets fed to pigs.

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