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Net energy of soybean oil and choice white grease in diets fed to growing and finishing pigs[1]

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ABSTRACT: The objectives of this experiment were 1) to determine the NE of soybean oil (SBO) and choice white grease (CWG) fed to growing and finishing pigs, 2) to evaluate the effects of inclusion rate of SBO on the NE by growing and finishing pigs, and 3) to determine if there is a difference in the NE of SBO and CWG between growing and finishing pigs. Forty-eight growing (initial BW: 22.13 ± 1.78 kg) and 48 finishing (initial BW: 84.17 ± 5.80 kg) barrows were used, and they were housed and fed individually. Within each stage of growth, pigs were allotted to 8 outcome groups of 6 barrows based on BW. Within each outcome group, pigs were randomly allotted to 1 of 6 groups. Two groups at each stage of growth served as an initial slaughter group. Pigs in the remaining groups were assigned to 4 dietary treatments and slaughtered at the conclusion of the experiment. The basal diet contained corn, soybean meal, and no supplemental lipids. Three additional diets were formulated by mixing 95% of the basal diet and 5% SBO, 90% of the basal diet and 10% SBO, or 90% of the basal diet and 10% CWG. Average daily gain and G:F for finishing pigs and apparent total tract digestibility of energy for growing and finishing pigs increased (linear, $P < 0.05$) with lipid content, but was not affected by lipid source. The lipid gain:protein gain ratio and the energy retention also increased (linear, $P \leq 0.05$) with lipid content in growing and finishing pigs. There were no interactive effects between lipid content and stage of growth or between lipid source and stage of growth on the NE of diets and the NE of dietary lipids. The NE of diets increased (linear, $P < 0.01$) with increasing SBO (2,056, 2,206, and 2,318 kcal/kg for diets containing 0, 5, or 10% SBO). The NE of the diet containing 10% CWG (2,440 kcal/kg) was greater ($P < 0.05$) than the NE of the diet containing 10% SBO. The NE of diets was greater ($P < 0.05$) for finishing pigs than for growing pigs regardless of lipid content or source. The NE of SBO included at 5% (5,073 kcal/kg) was not different from the NE of SBO included at 10% (4,679 kcal/kg), but the NE of CWG (5,900 kcal/kg) was greater ($P < 0.05$) than the NE of SBO. The stage of growth had no impact on the NE of SBO or CWG. In conclusion, the NE of lipids is not affected by the content of dietary lipids, but the NE of CWG is greater than the NE of SBO.

Key words: choice white grease, lipid content, net energy, pig, soybean oil, stage of growth

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INTRODUCTION

Lipids are important ingredients in swine diets because of their high energy concentration (Stahly, 1984). Currently, DE and ME systems are used in North America to predict the energy values of dietary lipids. However, these systems have been criticized because they do not account for the energetic efficiency of metabolizing dietary lipids (de Lange and Birkett, 2005), and DE and ME systems may underestimate the useful energy value of dietary lipids (Noblet et al., 1994). Therefore, it has been suggested that NE systems may allow for a more accurate prediction of the energy value of dietary lipids than DE and ME systems (Noblet et al., 1994).

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Dietary lipids are digested, absorbed, and either oxidized to yield energy in the form of ATP or incorporated into body lipids (Birkett and de Lange, 2001). In theory, the energetic efficiency of digested dietary lipids for ATP production is 66%, whereas the efficiency is 90% if they are directly incorporated into body lipids (Black, 1995). Therefore, the NE of dietary lipids is influenced not only by the digestibility, but also by the metabolic utilization (de Lange and Birkett, 2005). Both source and inclusion rate of dietary lipids may affect lipid digestibility (Stahly, 1984) and lipid metabolism in pigs (Allee et al., 1971, 1972). The stage of growth (growing pigs vs. finishing pigs) may also affect the metabolic utilization of dietary lipids because finishing pigs have a greater potential for lipid retention than growing pigs (de Greef et al., 1994).

The first objective of this experiment, therefore, was to determine the NE of 2 sources of dietary lipids [i.e., soybean oil (**SBO**) and choice white grease (**CWG**)], in growing and finishing pigs. The second objective was to measure the effects of inclusion rate of SBO on the NE, and the third objective was to compare the NE of lipids obtained by growing and finishing pigs.

Table 1. Analyzed composition of soybean oil and choice white grease (as-fed basis)

Composition	Soybean oil	Choice white grease
GE, Mcal/kg	9.38	9.41
Acid hydrolyzed ether extract, %	98.9	98.4
Total MIU,[1] %	0.93	1.33
Moisture, %	0.51	0.44
Insoluble impurities, %	0.14	0.32
Unsaponifiable matter, %	0.28	0.57
Fatty acid, % of sample		
Myristic (C14:0)	0.0	2.0
Palmitic (C16:0)	11.0	22.0
Palmitoleic (C16:1)	0.0	2.0
Stearic (C18:0)	5.0	12.0
Oleic (C18:1)	24.0	39.0
Linoleic (C18:2)	50.0	15.0
Linolenic (C18:3)	7.0	1.0
Eicosenoic (C20:1)	0.0	1.0
Eicosadienoic (C20:2)	0.0	1.0
SFA, %	17.0	38.0
PUFA, %	58.0	17.0
MUFA, %	24.0	43.0
Peroxide value, mEq/kg of fat	5.3	4.0

[1]Total of moisture, insoluble impurities, and unsaponifiable matter.

MATERIALS AND METHODS

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

Animals, Housing, and Experimental Design

The experiment was conducted using 48 growing and 48 finishing barrows that were the offspring of line 337 sires mated to C-22 females (Pig Improvement Company, Hendersonville, TN). The average initial BW was 22.13 ± 1.78 kg and 84.17 ± 5.80 kg for growing and finishing pigs, respectively. All pigs used in this experiment were selected based on BW and ADG during a 2-wk preexperimental period, during which pigs were fed a corn-soybean meal-based diet. Within each stage of growth, pigs were allotted to 8 outcome groups of 6 barrows according to BW. Within each outcome group, pigs were randomly allotted to 1 of 6 groups. Pigs allotted to 2 randomly selected groups at each stage of growth served as an initial slaughter group and all pigs in these 2 groups were slaughtered at the start of the experiment. The remaining 4 groups within each stage of growth were assigned to 4 dietary treatments, and all pigs in these 4 treatment groups were slaughtered at the conclusion of the experiment.

The experimental period was 28 d for growing pigs and 35 d for finishing pigs. Pigs were housed individually in 0.9 × 1.8 m pens in an environmentally controlled building located at the University of Illinois Swine Research Center. Average room temperature was 23°C for growing pigs and 19°C for finishing pigs. The room has a heater and a negative pressure ventilation system, and pens were equipped with a feeder, a nipple waterer, and a fully slatted concrete floor.

Dietary Treatments

Commercial sources of SBO (ADM, Decatur, IL) and CWG (Darling International, Indianapolis, IN) were procured and analyzed for chemical composition (Table 1). Four diets at each stage of growth were formulated (Table 2). The basal diets contained corn, soybean meal, chromic oxide, vitamins, and minerals, but no supplemental dietary lipids. At each stage of growth, the basal diet was formulated to contain at least 20% greater concentrations of all indispensable AA than current requirement estimates (NRC, 1998) to ensure that diets were adequate in AA when SBO or CWG was added. Vitamins and minerals were also included in the basal diet to exceed the estimated requirements (NRC, 1998). Within each stage of growth, 3 additional diets were formulated by mixing 95% of the basal diet and 5% SBO (as-is basis), 90% of the basal diet and 10% SBO (as-is basis), and 90% of the basal diet and 10% CWG (as-is basis). No antibiotic growth promoters were used, and all diets were provided in a meal form. Pigs were allowed ad libitum access to feed and water during the entire experimental period.

Collection of Data and Samples

The BW of pigs was recorded at the initiation of the experiment and at the end of each week thereafter. The

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

	Growing pigs				Finishing pigs			
Item	Basal	5% SBO	10% SBO	10% CWG	Basal	5% SBO	10% SBO	10% CWG
Ingredient, %								
Ground corn	67.55	64.17	60.80	60.80	78.94	74.98	71.05	71.05
Soybean meal, 47.5% CP	29.00	27.55	26.10	26.10	18.00	17.10	16.20	16.20
Soybean oil	—	5.00	10.00	—	—	5.00	10.00	—
Choice white grease	—	—	—	10.00	—	—	—	10.00
Dicalcium phosphate	1.40	1.33	1.26	1.26	1.00	0.95	0.90	0.90
Ground limestone	0.82	0.78	0.74	0.74	0.90	0.86	0.81	0.81
L-Lys HCl	0.17	0.16	0.15	0.15	0.10	0.10	0.09	0.09
Vitamin premix[2]	0.17	0.16	0.15	0.15	0.17	0.16	0.15	0.15
Mineral premix[3]	0.39	0.37	0.35	0.35	0.39	0.37	0.35	0.35
Cr_2O_3	0.50	0.48	0.45	0.45	0.50	0.48	0.45	0.45
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Energy and nutrients[4]								
DM, %	88.44	89.39	89.35	89.99	87.62	86.78	87.83	89.02
GE, Mcal/kg	3.87	4.12	4.38	4.38	3.81	4.05	4.36	4.39
CP, %	19.08	17.67	17.34	17.53	15.78	15.26	14.23	14.29
SID Lys, %	1.06	1.00	0.95	0.95	0.73	0.69	0.65	0.65
Ether extract, %	2.77	7.75	11.47	12.04	3.53	6.08	10.33	12.24
AEE,[5] %	3.24	8.57	13.70	13.10	4.67	8.55	13.15	14.62
Crude fiber, %	2.04	1.97	1.90	1.92	1.91	1.71	1.67	1.62
Ash, %	5.75	5.29	4.90	5.03	4.65	4.22	4.27	4.37
Ca, %	0.72	0.69	0.65	0.65	0.64	0.61	0.57	0.57
Relative bioavailable P, %	0.28	0.27	0.25	0.25	0.21	0.20	0.19	0.19

[1]Basal = basal diet; 5% SBO = diet containing 5% soybean oil; 10% SBO = diet containing 10% soybean oil; 10% CWG = diet containing 10% choice white grease.

[2]Vitamin premix provided the following quantities of vitamins per kilogram of basal diet: 11,234 IU of vitamin A as retinyl acetate; 1,156 IU of vitamin D as cholecalciferol; DL-α-tocopheryl acetate, 150 mg; menadione sodium bisulfite complex, 7 mg; riboflavin, 15 mg; vitamin B_{12}, 60 μg; D-Ca-pantothenic acid, 41 mg; niacin, 56 mg; and choline chloride, 551 mg.

[3]Mineral premix provided the following quantities of minerals per kilogram of basal diet: Fe, 100 mg ($FeSO_4 \cdot H_2O$); Zn, 111 mg (ZnO); Mn, 22 mg (MnO); Cu, 9 mg ($CuSO_4 \cdot H_2O$); I, 0.39 mg (CaI_2); Se, 0.33 mg (Na_2SeO_3); and NaCl, 3.3 g.

[4]Values for standardized ileal digestible (SID) Lys, Ca, and relative bioavailable P were calculated from NRC (1998); all other values were analyzed.

[5]AEE = acid-hydrolyzed ether extract.

allotment of feed to each pig was recorded daily, and feed left in the feeder was recorded on the same day as the BW of pigs was recorded. At the conclusion of the experiment, ADG, ADFI, and G:F for each pig were calculated and summarized within treatment and stage of growth.

Fresh fecal samples were collected on d 7 and weekly thereafter by grab sampling from each pig. Fecal samples were pooled within pig at the conclusion of the experiment, lyophilized, and finely ground before chemical analyses.

The comparative slaughter procedure was used to estimate the retention of energy, protein, and lipids in pigs fed each diet (de Goey and Ewan, 1975). The body composition of the 16 pigs that were slaughtered at the start of the experiment was measured and assumed to be representative for the initial body composition of all pigs included in the experiment. Assumed initial body composition was, therefore, calculated for each pig within the experiment and subtracted from values for final body composition to calculate gain of protein, lipid, and energy. Slaughter procedures and carcass measurements were described previously (Kil, 2008). In short, carcass, viscera, and blood were collected from each pig at slaughter and processed separately. The digestive tract was flushed with water to remove digesta. Carcasses and viscera were ground to obtain representative subsamples, and all subsamples of carcass, viscera, and blood were lyophilized and finely ground before chemical analyses.

Chemical Analyses

All analyses were performed in duplicate samples and analyses were repeated if results from duplicate samples varied more than 5% from the mean. The DM of diets and fecal samples was determined by oven drying at 135°C for 2 h (method 930.15; AOAC International, 2005). The DM of body components (i.e., carcass, viscera, and blood) was calculated by freeze drying to a constant weight. The GE of lipid sources, diets, feces, carcasses, viscera, and blood were measured using an adiabatic bomb calorimeter (model 6300, Parr Instruments, Moline, IL). Benzoic acid was used as the standard for calibration. The concentration of N in diets, feces, and body components was measured using the combustion method (method 990.03; AOAC International, 2005) with an apparatus (Elementar Rapid N-cube protein/N 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 lipids in diets and body components was determined using the petroleum ether extraction method (method 2003.06; AOAC International, 2005) and an automated analyzer (Soxtec 2050, FOSS North America, Eden Prairie, MN). The concentration of acid hydrolyzed ether extract in SBO, CWG, diets, and feces was measured after acid hydrolysis followed by ether extraction (Sanderson, 1986). Fatty acid concentrations in SBO and CWG were determined by gas chromatography (method 996.06; AOAC International, 2005), and values for peroxide, moisture, insoluble impurities, and unsaponifiable matter in SBO and CWG were determined using AOCS methods (AOCS, 1998). Diets and fecal samples were analyzed for chromium (Fenton and Fenton, 1979). The crude fiber concentration in diets was measured using the Weende method (method 962.09; AOAC International, 2005), and diets were also analyzed for ash (method 942.05; AOAC International, 2005).

Calculations

The apparent total tract digestibility (**ATTD**) of energy, CP, and acid ether extract in the diet fed to each treatment group was calculated according to Chastanet et al. (2007) based on the concentrations of chromic oxide in feed and feces. The ATTD of acid hydrolyzed ether extract in added lipids in diets containing 5% SBO, 10% SBO, or 10% CWG was calculated using the difference method (Adeola, 2001). The total quantity of energy, protein, and lipids in each pig at slaughter was calculated from the sum of the energy, protein, and lipids in the blood, viscera, and carcass. Retention of energy, protein, and lipids was calculated from the difference between the initial quantity of energy, protein, and lipids and the final quantity of energy, protein, and lipids, respectively (Oresanya et al., 2008). The initial body composition of the experimental pigs was determined from the body composition of pigs from the initial slaughter group (Oresanya et al., 2008). Energy retention was also calculated from protein gain and lipid gain as 5.66 and 9.46 kcal/g for protein and lipids, respectively (Ewan, 2001).

The daily NE_m for each pig was calculated by multiplying the mean metabolic BW ($kg^{0.6}$) by 179 kcal for both growing and finishing pigs (Noblet et al., 1994). The NE for each diet was then calculated from the sum of energy retention and the total NE requirement for maintenance during 28 d for growing pigs and 35 d for finishing pigs (Ewan, 2001). The NE of SBO and CWG were subsequently calculated using the difference method by subtracting the NE contribution from the basal diet from the NE of the diets containing SBO or CWG (de Goey and Ewan, 1975).

Statistical Analyses

All data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC) with the pig as the experimental unit. Homogeneity of the variances was verified using the UNIVARIATE procedure of SAS. The residual vs. the predicted plot procedure was used to analyze for outliers. One finishing pig was identified as an outlier, and this pig was excluded from the analysis. Diet was the main effect in the model. The LSMEANS procedure was used to calculate mean values. Orthogonal polynomial contrasts were used to determine linear and quadratic effects of the inclusion rate of SBO on growth performance, nutrient digestibility, carcass measurements, retention of protein, lipids, and energy, and the NE of diets at each stage of growth. A single degree of freedom contrast analysis was conducted to compare treatment means for pigs fed diets containing 10% SBO and 10% CWG, respectively. An additional analysis was conducted to analyze effects of lipid source, lipid content, and stage of growth on NE of diets and lipids. The interactions between lipid content and stage of growth and between lipid source and stage of growth for the NE of diets or lipids were also analyzed, but these interactions were not significant for any of the calculated values, and the interaction terms were, therefore, removed from the final analyses. A probability of $P < 0.05$ was considered significant, and $0.05 < P < 0.10$ was considered a tendency.

RESULTS

Pig Performance and Digestibility of Energy and Nutrients

Final BW, ADG, and ADFI for growing pigs were not affected by dietary content or source of lipids, but a trend (linear, $P = 0.08$) for an increase in G:F was observed as dietary lipids increased (Table 3).The ADG and G:F for finishing pigs increased (linear, $P < 0.05$) with increasing dietary lipids, but was not affected by lipid source. A trend ($P = 0.06$) for greater ADFI was observed for finishing pigs fed diets containing 10% SBO compared with finishing pigs fed diets containing 10% CWG. For both growing and finishing pigs, the ATTD of energy in diets increased (linear, $P < 0.01$) as dietary lipids increased. The ATTD of acid hydrolyzed ether extract in diets also increased (linear and quadratic, $P < 0.01$) with lipid content. The ATTD of CP in diets was not affected by lipid content for growing pigs, but a trend (linear, $P = 0.09$) for an increase in ATTD of CP by increasing lipid was observed for finishing pigs. The ATTD of dietary acid hydrolyzed ether extract tended to be greater ($P = 0.07$) for growing pigs fed diets containing 10% SBO than for growing pigs fed diets containing 10% CWG, whereas no difference was observed for finishing pigs. For growing pigs, the ATTD of acid ether extract from 5% SBO (97.0%), 10% SBO (94.8%), and 10% CWG (93.7%) were not different.

Table 3. Effect of dietary soybean oil (SBO) and choice white grease (CWG) on growth performance and apparent total tract digestibility (ATTD) of energy and nutrients by growing and finishing pigs[1]

Item	Dietary treatment[2]				Lipid content			Lipid source	
						P-value[3]			
	Basal	5% SBO	10% SBO	10% CWG	SEM	Lin	Q	SEM	*P*-value[4]
Growing pigs									
Initial BW, kg	22.19	22.06	22.31	22.56	0.678	0.90	0.82	0.679	0.50
Final BW, kg	49.44	50.00	50.69	52.19	1.450	0.55	0.97	1.436	0.47
ADG, kg	0.973	0.998	1.014	1.058	0.037	0.45	0.93	0.047	0.15
ADFI, kg	1.887	1.879	1.872	1.980	0.072	0.88	0.99	0.071	0.30
G:F, kg/kg	0.517	0.531	0.543	0.533	0.010	0.08	0.88	0.011	0.56
ATTD, GE, %	81.04	83.06	84.05	84.06	0.523	<0.01	0.44	0.578	0.99
ATTD, CP, %	77.96	78.37	78.47	79.67	0.789	0.65	0.87	0.766	0.29
ATTD, AEE[5] in diets, %	33.19	74.20	82.35	80.52	1.427	<0.01	<0.01	0.656	0.07
ATTD, AEE of added lipids,[6] %	—	96.97	94.77	93.67	1.241	—	—	0.921	0.41
Finishing pigs									
Initial BW, kg	85.56	84.56	85.71	83.13	2.245	0.96	0.68	1.980	0.36
Final BW, kg	127.88	130.31	135.64	127.81	3.380	0.11	0.72	4.062	0.18
ADG, kg	1.209	1.307	1.427	1.277	0.054	0.01	0.87	0.080	0.19
ADFI, kg	3.701	3.561	3.858	3.274	0.156	0.47	0.24	0.207	0.06
G:F, kg/kg	0.326	0.368	0.375	0.388	0.014	0.02	0.29	0.015	0.54
ATTD, GE, %	82.66	85.10	87.08	86.74	0.464	<0.01	0.68	0.420	0.57
ATTD, CP, %	79.36	81.21	81.60	82.22	0.928	0.09	0.51	0.617	0.47
ATTD, AEE in diets, %	49.13	73.11	82.10	81.93	1.231	<0.01	<0.01	0.949	0.90
ATTD, AEE of added lipids, %	—	98.44	96.98	94.44	1.822	0.57	—	1.598	0.27

[1]Data are least squares means of 8 observations per treatment, except for the finishing pigs fed the diet containing 10% soybean oil, where data are least squares means of 7 observations.

[2]Basal = basal diet; 5% SBO = diet containing 5% SBO; 10% SBO = diet containing 10% SBO; 10% CWG = diet containing 10% CWG.

[3]*P*-values for linear (Lin) and quadratic (Q) effects are for the effects of lipid content in diets among basal, 5% SBO, and 10% SBO.

[4]*P*-value for lipid source is based on contrast analyses between 10% SBO and 10% CWG.

[5]AEE = acid-hydrolyzed ether extract.

[6]The ATTD of added lipids was calculated using the difference procedure (Adeola, 2001) and represents the ATTD for added SBO or CWG.

Likewise, for finishing pigs, no effects of lipid content or source on the ATTD of acid hydrolyzed ether extract were observed (98.4, 97.0, and 94.4% for 5% SBO, 10% SBO, and 10% CWG, respectively).

Carcass Composition and Retention of Energy, Protein, and Lipids

In the growing phase, BW, HCW, and dressing percentage were not influenced by dietary content or source of lipids (Table 4). The weight of the total digesta-free body DM increased (linear, $P < 0.05$) as dietary lipids increased. Total quantity of energy, the lipid gain:protein gain ratio, and measured energy retention increased (linear, $P < 0.05$) with increasing lipids, but protein gain was not affected by the content of dietary lipids. A trend (linear, $P = 0.07$) for an increase in lipid gain was observed as the content of dietary lipids increased. Lipid gain, lipid gain:protein gain ratio, and calculated energy retention was greater ($P < 0.01$) for pigs fed the diet containing 10% CWG than for pigs fed the diet containing 10% SBO. Measured energy retention also tended to be greater ($P = 0.06$) for pigs fed the diet containing 10% CWG than for pigs fed the diet containing 10% SBO.

In the finishing phase, HCW increased (linear, $P < 0.05$) with increasing level of dietary lipids, but that was not the case for BW and dressing percentage (Table 5). Body weight, HCW, and dressing percentage were not affected by lipid source. Likewise, the weight of the digesta-free body DM was not influenced by dietary content or source of lipids. The total quantity of protein, lipids, and energy, protein gain, and lipid gain were not affected by the dietary content or source of lipids, but the lipid gain:protein gain ratio increased (linear, $P < 0.05$) with increasing content of dietary lipids. A trend (linear, $P = 0.05$) for an increase in measured energy retention was also observed as the content of dietary lipids increased, but the calculated energy retention was not influenced by the content or source of dietary lipids.

NE of Diets and Supplemental Lipids

For growing pigs, no differences among treatment groups in initial body energy were observed, but the final quantity of energy, energy retention, and NE intake increased (linear, $P < 0.05$) as the content of dietary lipids increased (Table 6). The final quantity of energy in the digesta-free body was greater ($P < 0.05$) for pigs

Table 4. Effect of dietary soybean oil (SBO) and choice white grease (CWG) on carcass composition and retention of energy, protein, and lipids in growing pigs[1,2]

						Lipid content				
		Dietary treatment[4]					*P*-value[5]		Lipid source	
Item	ISG[3]	Basal	5% SBO	10% SBO	10% CWG	SEM	Lin	Q	SEM	*P*-value[6]
BW, kg	19.43	46.68	47.33	48.58	50.13	1.350	0.33	0.86	1.221	0.39
HCW, kg	16.05	37.23	38.55	39.00	40.33	1.151	0.29	0.76	1.094	0.41
Dressing percentage, %	82.83	79.78	81.47	80.22	80.45	0.643	0.63	0.08	0.400	0.70
Carcass composition										
DF BW,[7] kg	19.12	44.67	45.72	46.75	48.34	1.269	0.26	0.99	1.147	0.34
DF BW, kg DM	5.62	15.49	16.25	17.25	18.34	0.565	0.04	0.86	0.566	0.20
Total protein, kg/pig	3.24	7.81	7.85	7.63	7.84	0.275	0.65	0.70	0.190	0.45
Total lipids, kg/pig	1.48	5.56	6.34	6.44	8.54	0.350	0.09	0.43	0.417	<0.01
Total energy, Mcal/pig	32.65	96.67	102.96	110.03	123.37	4.061	0.03	0.94	4.369	<0.05
Retention										
Protein gain, g/d	—	161.3	163.5	154.2	160.3	7.97	0.54	0.57	5.62	0.46
Lipid gain, g/d	—	144.8	173.3	176.1	250.5	11.68	0.07	0.38	14.92	<0.01
Lipid:protein,[8] g/g	—	0.91	1.07	1.14	1.57	0.076	0.04	0.67	0.092	<0.01
MER,[9] Mcal/d	—	2.27	2.50	2.74	3.20	0.122	0.01	0.98	0.157	0.06
CER,[10] Mcal/d	—	2.28	2.56	2.54	3.28	0.133	0.19	0.36	0.154	<0.01

[1]Data are least squares means.
[2]n = 16 for initial slaughter group; n = 8 for all other treatments.
[3]ISG = initial slaughter group.
[4]Basal = basal diet; 5% SBO = diet containing 5% SBO; 10% SBO = diet containing 10% SBO; 10% CWG = diet containing 10% CWG.
[5]*P*-values for linear (Lin) and quadratic (Q) effects are for the effects of lipid level in diets among basal, 5% SBO, and 10% SBO.
[6]*P*-value for lipid source is based on contrast analyses between 10% SBO and 10% CWG.
[7]DF BW = digesta-free BW, which is the sum of the weight of the chilled carcass, empty viscera, and blood.
[8]Lipid:protein = the ratio of daily lipid gain to daily protein gain.
[9]MER = measured energy retention.
[10]CER = calculated energy retention (calculated from protein and lipid gain as 5.66 and 9.46 kcal/g for protein and lipid, respectively; Ewan, 2001).

fed the diet containing 10% CWG than for pigs fed the diet containing 10% SBO, and energy retention and NE intake tended to be greater ($P = 0.06$) for pigs fed the diet containing 10% CWG than for pigs fed the diet containing 10% SBO.

The NE of diets increased (linear, $P < 0.01$) as dietary SBO increased (1,985, 2,113, and 2,264 kcal/kg for diets containing 0, 5, and 10% SBO, respectively). The NE of the diet containing 10% CWG (2,377 kcal/kg) tended to be greater ($P = 0.08$) than the NE of the diet containing 10% SBO. The NE of SBO included at 5% (4,561 kcal/kg) was not different from the NE of SBO included at 10% (4,781 kcal/kg), but the NE of CWG (5,908 kcal/kg) tended to be greater ($P = 0.08$) than the NE of SBO.

For finishing pigs, no differences in initial or final quantity of body energy were observed among treatment groups, but a trend for an increase in energy retention (linear, $P = 0.05$) and NE intake (linear, $P = 0.06$) was observed as the content of dietary lipids increased. However, energy retention and NE intake were not affected by lipid source. The NE of diets increased (linear, $P < 0.05$) as the content of dietary lipids increased (2,127, 2,299, and 2,372 kcal/kg for diets containing 0, 5, and 10% SBO, respectively). The NE of diets containing 10% CWG (2,503 kcal/kg) was not different from the NE of diets containing 10% SBO. The NE of SBO included at 5% (5,585 kcal/kg) was not different from the NE of SBO included at 10% (4,578 kcal/kg), and the NE of CWG (5,892 kcal/kg) was not different from the NE of SBO.

There was no interaction between lipid content and stage of growth or between lipid source and stage of growth, and therefore, the main effects of lipid content, lipid source, and stage of growth on NE of diets and lipids were calculated (Table 7). The NE of diets increased (linear, $P < 0.01$) with increasing SBO (2,056, 2,206, and 2,318 kcal/kg for diets containing 0, 5, and 10% SBO, respectively). The NE of the diet containing 10% CWG (2,440 kcal/kg) was greater ($P < 0.05$) than the NE of the diet containing 10% SBO. The NE of diets was greater ($P < 0.01$) for finishing pigs than for growing pigs regardless of lipid content or source. The NE of SBO included at 5% (5,073 kcal/kg) was not different from the NE of SBO included at 10% (4,679 kcal/kg), but the NE of CWG (5,900 kcal/kg) was greater ($P < 0.05$) than the NE of SBO. Stage of growth had no influence on the NE of dietary lipids.

DISCUSSION

The composition of fatty acids in SBO and CWG corresponds with published values (NRC, 1998; Engel et al., 2001). The fatty acid composition of CWG used

Table 5. Effect of dietary soybean oil (SBO) and choice white grease (CWG) on carcass composition and retention of energy, protein, and lipids in finishing pigs[1,2]

						Lipid content				
		Dietary treatment[4]					*P*-value[5]		Lipid source	
Item	ISG[3]	Basal	5% SBO	10% SBO	10% CWG	SEM	Lin	Q	SEM	*P*-value[6]
BW, kg	82.89	122.58	126.18	131.03	123.38	3.262	0.07	0.87	4.146	0.20
HCW, kg	65.12	108.63	112.50	118.74	111.75	2.949	0.02	0.73	3.574	0.18
Dressing percentage, %	78.55	88.63	89.18	90.66	90.61	0.875	0.11	0.65	0.392	0.93
Carcass composition										
DF BW,[7] kg	80.56	118.76	122.40	127.27	119.76	3.182	0.07	0.87	3.990	0.19
DF BW, kg DM	32.92	55.90	56.98	61.33	56.41	2.129	0.08	0.52	2.277	0.14
Total protein, kg/pig	13.12	19.30	18.55	18.28	18.70	0.623	0.25	0.74	0.601	0.62
Total lipids, kg/pig	16.57	31.84	33.24	34.45	32.82	1.522	0.23	0.96	1.658	0.49
Total energy, Mcal/pig	227.1	405.5	411.4	444.1	409.5	17.25	0.12	0.51	17.84	0.18
Retention										
Protein gain, g/d	—	171.5	154.6	141.9	165.3	13.80	0.13	0.90	14.34	0.25
Lipid gain, g/d	—	430.7	476.2	504.2	472.1	36.09	0.15	0.84	39.90	0.57
Lipid:protein,[8] g/g	—	2.52	3.19	3.89	2.95	0.376	0.02	0.98	0.469	0.17
MER,[9] Mcal/d	—	5.02	5.27	6.11	5.32	0.384	0.05	0.51	0.403	0.18
CER,[10] Mcal/d	—	5.05	5.38	5.57	5.40	0.364	0.30	0.87	0.392	0.76

[1]Data are least squares means.
[2]n = 16 for initial slaughter group; n = 8 for all other treatments, except for pigs fed the diet containing 10% soybean oil, where n = 7.
[3]ISG = initial slaughter group.
[4]Basal = basal diet; 5% SBO = diet containing 5% SBO; 10% SBO = diet containing 10% SBO; 10% CWG = diet containing 10% CWG.
[5]*P*-values for linear (Lin) and quadratic (Q) effects are for the effects of lipid level in diets among basal, 5% SBO, and 10% SBO.
[6]*P*-value for lipid source is based on contrast analyses between 10% SBO and 10% CWG.
[7]DF BW = digesta-free BW, which is the sum of the weight of the chilled carcass, empty viscera, and blood.
[8]Lipid:protein = the ratio of daily lipid gain to daily protein gain.
[9]MER = measured energy retention.
[10]CER = calculated energy retention (calculated from protein and lipid gain as 5.66 and 9.46 kcal/g for protein and lipid, respectively; Ewan, 2001).

in this experiment is also comparable with fatty acid compositions in lipids from pigs or poultry (Jørgensen and Fernández, 2000). The values for peroxide, moisture, insoluble impurities, and unsaponifiable matter were considered normal, and none of these values would indicate that the 2 sources of lipids used in this experiment were rancid or otherwise of poor quality.

Pig Performance and Nutrient Digestibility

The improved G:F for growing and finishing pigs as a result of increasing amount of dietary lipids agrees with previous observations (Pettigrew and Moser, 1991; Øverland et al., 1999; De la Llata et al., 2001). However, it was unexpected that the amount of dietary lipids did not influence ADFI for growing or finishing pigs because pigs often reduce feed intake as the dietary energy concentration increases (Pettigrew and Moser, 1991; De la Llata et al., 2001). However, dietary energy concentration is not the only factor that determines feed intake (Black, 1995; Giles et al., 1998; Nyachoti et al., 2004). Other factors such as the number of pigs in a pen (Gomez et al., 2000; Hyun and Ellis, 2001), ambient temperature, health status of pigs, and physical properties of feed may also affect feed intake of pigs (Whittemore et al., 2001; Nyachoti et al., 2004). Nevertheless, the feed intake and the ADG that were observed in this experiment are greater than what is usually observed for growing and finishing pigs, and this is likely a consequence of the fact that there was only 1 pig per pen and that diets were relatively high in energy.

The increases in ATTD of energy that were observed with increasing content of dietary lipids for both growing and finishing pigs may be a result of the greater digestibility and energy density of added lipids compared with those of basal diets containing no added lipids. The reason the ATTD of lipids in the diets increased as the amount of lipids in the diets increased is most likely that added lipids have a greater digestibility than lipids present in an intact ingredient such as corn (Kil et al., 2010). In addition, the relative effects of endogenous losses of lipids on the ATTD of lipids decreases as the concentration of dietary lipids increases, which also leads to a greater measured value for ATTD of lipids as the concentration of dietary lipids increases (Jørgensen et al., 1993; Kil et al., 2010).

Saturated lipids may be less digestible than unsaturated lipids (Wiseman et al., 1990; Powles et al., 1994; Scheeder et al., 2003), but we were not able to verify this hypothesis because the ATTD of lipids was similar for pigs fed diets containing SBO or CWG. However, results of this experiment concur with Jørgensen and Fernández (2000), who reported that lipid digestibility

Table 6. Net energy of diets and dietary lipids in growing and finishing pigs[1]

Item	Dietary treatment[2]				Lipid content			Lipid source	
						P-value[3]			
	Basal	5% SBO	10% SBO	10% CWG	SEM	Lin	Q	SEM	*P*-value[4]
Growing pigs									
Initial body energy, Mcal	33.20	33.02	33.39	33.76	1.014	0.90	0.82	1.017	0.80
Final body energy, Mcal	96.67	102.96	110.03	123.37	4.061	0.03	0.94	4.369	<0.05
Energy retention, Mcal	63.47	69.94	76.64	89.61	3.407	0.01	0.98	4.387	0.06
Total NE_m,[5] Mcal	41.01	41.29	41.64	42.23	0.681	0.54	0.98	0.561	0.45
Total NE intake, Mcal	104.48	111.24	118.26	131.84	3.947	0.02	0.98	4.612	0.06
Total feed intake, kg	52.83	52.60	52.40	55.45	2.005	0.88	0.99	1.994	0.30
NE of diets, kcal/kg	1,985	2,113	2,264	2,377	42.2	<0.01	0.83	42.0	0.08
NE of lipids,[6] kcal/kg	—	4,561	4,781	5,908	476.5	0.75	—	419.9	0.08
Finishing pigs									
Initial body energy, Mcal	229.80	227.12	230.21	223.26	6.03	0.96	0.68	5.32	0.36
Final body energy, Mcal	405.54	411.43	444.07	409.53	17.25	0.12	0.51	17.84	0.18
Energy retention, Mcal	175.74	184.31	213.86	186.28	13.43	0.05	0.51	14.09	0.18
Total NE_m,[5] Mcal	101.55	101.87	103.41	100.59	1.56	0.40	0.74	1.62	0.23
Total NE intake,[6] Mcal	277.29	286.19	317.27	286.86	14.37	0.06	0.51	15.45	0.17
Total feed intake, kg	129.53	124.63	135.03	114.60	5.46	0.47	0.24	7.25	0.06
NE of diets, kcal/kg	2,127	2,299	2,372	2,503	75.9	0.03	0.57	65.8	0.17
NE of lipids,[7] kcal/kg	—	5,585	4,578	5,892	960.9	0.46	—	658.0	0.17

[1]Data are least squares means of 8 observations per treatment, except for the finishing pigs fed the diet containing 10% soybean oil, where data are least squares means of 7 observations.

[2]Basal = basal diet; 5% SBO = diet containing 5% soybean oil (SBO); 10% SBO = diet containing 10% SBO; 10% CWG = diet containing 10% choice white grease (CWG).

[3]*P*-values for linear (Lin) and quadratic (Q) effects are for the effects of lipid level in diets among basal, 5% SBO, and 10% SBO.

[4]*P*-value for lipid source is based on contrast analyses between 10% SBO and 10% CWG.

[5]Total NE_m was calculated by multiplying the mean metabolic BW ($kg^{0.6}$) of each pig by 179 kcal (Noblet et al., 1994) and the number of days the pigs were fed experimental diets.

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

[7]NE of lipids = SBO included at 5%, SBO included at 10%, and CWG included at 10%. The NE of SBO and CWG were calculated using the difference method by subtracting the NE contribution from the basal diet from the NE of the diets containing SBO or CWG (de Goey and Ewan, 1975).

of dietary fats of animal or vegetable origins are not different.

Carcass Composition and Retention of Energy, Protein, and Lipids

The protein gain in growing (161 g/d) and finishing pigs (171 g/d) fed the basal diet is slightly greater than the values reported by Quiniou et al. (1996) who suggested that the potential maximum for protein gain is 151 g/d for growing and finishing pigs allowed free access to feed. The difference in protein gain may be explained by the differences in diet composition, environment, and genetics among experiments (Verstegen et al., 1995; Quiniou et al., 1996), and the greater ADFI and ADG that were observed in this experiment may have also contributed to the slightly greater protein gain. The daily intake of digestible Lys and other indispensable AA was also greater in this experiment than in previous experiments, which may have contributed to the greater protein gain. The increase in lipid gain:protein gain ratio and in energy retention that was observed in both growing and finishing pigs as the content of dietary lipids increased is likely due to increased lipid gain with no change in protein gain, which is an often observed response to increased dietary lipids in pigs (Stahly, 1984).

NE of Diets and Supplemental Lipids

The values for NE of diets for growing and finishing pigs measured in this experiment are less than the values that may be calculated from the NE of each ingredient (Sauvant et al., 2004). Differences in NE values of diets between experiments may be attributed to different methodologies to measure energy retention because energy retention measured by indirect calorimetry, which was used by Sauvant et al. (2004), may be greater than values calculated from the comparative slaughter method that was used in this experiment (Quiniou et al., 1995; Reynolds, 2000). Differences in genetics, feeding strategy, environment, and BW of pigs, which affect maintenance, growth, and body composition, between experiments may also contribute to variation in the NE values of diets and ingredients (Boisen and Verstegen, 1998).

The values for NE of SBO and CWG calculated in this experiment (4,679 and 5,900 kcal/kg, respectively) are less than the value for NE of both sources of lipids (7,120 kcal/kg) that was suggested by Sauvant et al.

(2004). However, the NE values obtained in the present experiment are greater than the values of 4,190 and 4,170 kcal/kg of DM reported for tallow by Galloway and Ewan (1989). In the present experiment and in the experiment by Galloway and Ewan (1989), the difference procedure was used to measure NE values, whereas the value reported by Sauvant et al. (2004) is a calculated value.

The increase in the NE of diets with increasing dietary lipids that was observed in this experiment agrees with previous observations (Just, 1982) and is a consequence of the greater NE of lipids than of corn and soybean meal. Dietary lipids also increase the ileal digestibility of AA (Cervantes-Pahm and Stein, 2008) and may reduce the proportion of energy that is absorbed from the hindgut of pigs where the absorbed energy has a reduced energetic efficiency compared with energy absorbed in the small intestine (Just, 1982; Noblet et al., 1994).

There were no effects of inclusion rate of lipids on the NE of SBO. In theory, at the smaller inclusion rate of dietary lipids, the majority of the digested lipids may be directly incorporated into body lipids, which has an energetic efficiency of 90% (Black, 1995). When the greater quantity of lipids was included in the diet, a greater proportion of the digested lipids was expected to be oxidized for ATP synthesis, which has an energetic efficiency of 66% (Black, 1995). Accordingly, it was expected that increasing inclusion rates of dietary lipids will decrease the NE of lipids. However, we failed to detect a statistically significant difference in the NE of SBO included at 5 or 10%. Therefore, the results of this experiment indicate that the proportion of dietary lipids that are used for ATP synthesis and for incorporation into body tissue, respectively, is similar for diets containing 5 or 10% SBO. It should, however, be noted that one of the inherent problems associated with using the difference procedure is that values obtained with this procedure are surrounded with relatively large SEM values. This is particularly true if the inclusion rate of the ingredient is small as was the case in this experiment, and the SEM values for the NE of lipids were more than 10 times greater than the SEM values for the NE of the diets. The SEM values for ME of ingredients are also much greater than SEM values for diets when the difference procedure is used (Baker and Stein, 2009). However, the difference procedure is the only procedure that is available to measure the NE of lipids, and because of the assumed different efficiencies in the utilization of lipids included in diets at high and low inclusion rates, it was necessary to have relatively small inclusion rates of lipids in this experiment.

If determined NE values for the diets are expressed as percentages of DE values calculated by multiplying the ATTD of GE by the GE of each diet, values between 60 and 68% are obtained for all diets. These values are in close agreement with values previously reported for diets containing between 4 and 23% fat (Just, 1982) and slightly less than the average value of 71% reported by

Table 7. Effect of dietary content and source of lipids on NE of diets and dietary lipids fed to growing and finishing pigs

	Lipid content[1]					Lipid source[2]				Lipid content[1]			Lipid source[2]		
				Stage[3]				Stage[3]			*P*-value[4]			*P*-value[5]	
Item	0% SBO	5% SBO	10% SBO	Grow	Fin	10% SBO	10% CWG	Grow	Fin	SEM	Content[6]	Stage	SEM	Source	Stage
NE of diets[7]	2,056	2,206	2,318	2,121	2,266	2,318	2,440	2,321	2,437	62.1	<0.01	<0.01	55.9	0.03	0.04
NE of lipids[8]	—	5,073	4,679	4,671	5,082	4,679	5,900	5,345	5,235	761.1	0.59	0.58	559.4	0.03	0.84

[1]Lipid content = 0, 5, and 10% soybean oil (SBO); n = 16 for 0 and 5% SBO, and n = 15 for 10% SBO.
[2]Lipid source = 10% SBO and 10% choice white grease (CWG).
[3]Stage of growth = growing pigs (Grow) and finishing pigs (Fin); n = 24 for Grow and n = 23 for Fin.
[4]*P*-values for the effects of lipid content and stage of growth on NE of diets and lipids. No interaction was observed between lipid content and stage of growth.
[5]*P*-values for the effects of lipid source and stage of growth on NE of diets and lipids. No interaction was observed between lipid source and stage of growth.
[6]Linear effect of lipid content on the NE of diets, $P < 0.01$.
[7]NE of diets containing 0, 5, or 10% SBO or 10% CWG (kcal/kg).
[8]NE of lipids = NE of SBO included at 5%, NE of SBO included at 10%, and NE of CWG included at 10% (kcal/kg).

Noblet et al. (1994) for diets containing between 1 and 11% fat. If the same calculation is completed for SBO and CWG, values between 50 and 60% are obtained for SBO and values of 67 and 66% are obtained for CWG. These data are greater than values between 50 and 52% reported for tallow fed to weanling pigs (Galloway and Ewan, 1989), but they are less than values around 90% reported by Noblet et al. (1994). The reason for these differences may be that indirect calorimetry was used by Noblet et al. (1994), whereas the slaughter procedure and the difference method were used by Galloway and Ewan (1989) and in the present experiment.

The fact that the NE as percentage of DE is not greater for the lipid sources than for the diets indicates that the energetic efficiency of lipids is not greater than that of protein and carbohydrates, which in turn would indicate that most of the lipids are oxidized rather than directly deposited in adipose tissue. This conclusion agrees with the data by Galloway and Ewan (1989) and also explains the lack of a difference in NE for 5 and 10% SBO as discussed above.

The greater calculated NE of the diet containing 10% CWG than of the diet containing 10% SBO may be a result of the increased lipid retention in pigs fed the diet containing 10% CWG. The fatty acids in SBO are more unsaturated than fatty acids in CWG and, therefore, may increase the maintenance requirement for pigs because unsaturated fatty acids may increase the oxidative stress in pigs (López Bote et al., 2001). Fatty acids in SBO may also increase the rate of turnover of triacylglyceride in adipose tissue because unsaturated fatty acids may be more easily mobilized from triacylglyceride (Raclot and Oudart, 1999) and more rapidly incorporated into body lipids (Karola et al., 2002) compared with SFA. Polyunsaturated fatty acids may also increase the rate of β-oxidation via the activation of carnitine palmitoyl transferase (Gavino and Gavino, 1991) and increase the activity of lipoprotein lipase in muscle (Shimomura et al., 1990), which further contributes to a rapid oxidation of unsaturated fatty acids (Cunnane, 2004; Kloareg et al., 2007; van den Borne et al., 2009). Therefore, a greater proportion of fatty acids in SBO may be oxidized for ATP synthesis compared with fatty acids in CWG. Consequently, the NE of dietary lipids containing SFA may be greater than the NE of dietary lipids containing unsaturated fatty acids, which explains the greater NE of CWG than of SBO observed in this experiment. The tendency for a greater lipid deposition in growing pigs fed CWG compared with growing pigs fed SBO further supports this hypothesis.

The greater NE of diets for finishing pigs than for growing pigs regardless of the content or source of lipids is a consequence of finishing pigs having a greater digestibility of energy and nutrients (Noblet and Shi, 1994) and a greater potential for lipid gain than growing pigs (de Greef et al., 1994). Diets fed to finishing pigs also contained more corn and less soybean meal than diets fed to growing pigs. The NE of corn is greater than the NE of soybean meal (Sauvant et al., 2004), and this difference in diet composition may, therefore, be another reason for the greater NE of diets for finishing pigs than for growing pigs.

It was hypothesized that the NE of SBO and CWG is greater for finishing pigs than for growing pigs because finishing pigs have a greater potential for lipid gain than growing pigs (de Greef et al., 1994). However, the NE of lipids did not differ between growing and finishing pigs, indicating that the digested lipids may be used at a relatively constant rate for incorporation into body lipids or for ATP synthesis in growing and finishing pigs. It is possible that the quantities of dietary lipids that are directly deposited in adipose tissue may be relatively small and that most dietary lipids are oxidized after absorption. This hypothesis also explains the lack of a difference between the NE for SBO included at 5 and 10% and the relatively low NE-to-DE ratio for lipids that was observed in this experiment as well as in other experiments.

The lack of interactions between lipid content and stage of growth and between lipid source and stage of growth indicates that the effects of lipid content and lipid source on the NE of lipids are independent of the stage of growth. We are not aware of any other data that have examined these effects.

In conclusion, results from this experiment indicate that the NE of diets containing CWG is greater than the NE of diets containing SBO. The NE of diets is also greater for finishing pigs than for growing pigs. The NE of SBO included at 5% in a corn-soybean meal diet is not different from the NE of SBO included at 10%. The NE of CWG is greater than the NE of SBO, which indicates that lipids containing increased amounts of SFA have a greater NE value than lipids containing greater amounts of unsaturated fatty acids. Stage of growth has no influence on the NE of SBO or CWG.

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