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Effects of dietary soybean oil on pig growth performance, retention of protein, lipids, and energy, and the net energy of corn in diets fed to growing or finishing pigs[1]

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ABSTRACT: The objectives of this experiment were 1) to determine if dietary soybean oil (SBO) affects the NE of corn when fed to growing or finishing pigs, 2) to determine if possible effects of dietary SBO on the NE of corn differ between growing and finishing pigs, and 3) to determine effects of SBO on pig growth performance and retention of energy, protein, and lipids. Forty-eight growing (initial BW: 27.3 ± 2.5 kg) and 48 finishing (initial BW: 86.0 ± 3.0 kg) barrows were used, and within each stage of growth, pigs were allotted to 1 of 6 groups. Two groups at each stage of growth served as an initial slaughter group. The remaining 4 groups were randomly assigned to 4 dietary treatments and pigs in these groups were harvested at the conclusion of the experiment. A low-lipid basal diet containing corn, soybean meal, and no added SBO and a high-lipid basal diet containing corn, soybean meal, and 8% SBO were formulated at each stage of growth. Two additional diets at each stage of growth were formulated by mixing 25% corn and 75% of the low-lipid basal diet or 25% corn and 75% of the high-lipid basal diet. Results indicated that addition of SBO had no effects on growth performance, carcass composition, or retention of energy, protein, and lipids but increased ($P < 0.05$) apparent total tract digestibility of acid hydrolyzed ether extract and GE. Addition of SBO also increased ($P < 0.05$) DE and NE of diets, but had no effect on the DE and NE of corn. Finishing pigs had greater ($P < 0.05$) growth performance and retention of energy, protein, and lipids than growing pigs. A greater ($P < 0.05$) DE and NE of diets was observed for finishing pigs than for growing pigs and the DE and NE of corn was also greater ($P < 0.05$) for finishing pigs than for growing pigs. In conclusion, addition of SBO increases the DE and NE of diets but has no impact on the DE and NE of corn. Diets fed to finishing pigs have greater DE and NE values than diets fed to growing pigs and the DE and NE of corn are greater for finishing pigs than for growing pigs.

Key words: corn, energy retention, net energy, pig, soybean oil, stage of growth

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INTRODUCTION

Corn is the main energy source for most swine diets in the United States and starch, which is the major energy-containing nutrient in corn, can be metabolized to ATP or used for the synthesis of glycerol and fatty acids that are subsequently stored as body lipids. If pigs are fed diets containing high amounts of dietary lipids, it is likely that most of the starch in corn is used for ATP instead of being converted to body lipids, but if only small amounts of lipids are present in the diet, some of the starch in corn is used for glycerol and fatty acid synthesis (Jakobsen and Thorbek, 1993). The theoretical energetic efficiency of metabolizing glucose to ATP

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is 68% whereas the theoretical efficiency of using glucose for fatty acid synthesis is 74 to 84% (Black, 1995; Van Milgen et al., 2001). It is, therefore, possible that the energy value of corn is less if high amounts of lipids are added to the diets than if no lipids are used. It is also expected that the impact of dietary lipids on the energy value of corn may depend on the BW of pigs because finishing pigs retain more lipids than growing pigs (de Greef et al., 1994).

However, no experiments have been conducted to investigate these hypotheses, and it is not known if dietary lipids influence the retention of energy, protein, and lipids in pigs as a result of a changed energetic use of corn. Energy systems based on DE or ME do not consider the differences in the energetic use of starch used for ATP or fatty acid synthesis, but the NE system accounts for this difference. The objective of this experiment was to test the hypothesis that the NE of corn is reduced if soybean oil (**SBO**) is included in the diet, that pig growth performance and the retention of protein, lipids, and energy in pigs is affected by the concentration of SBO in the diet, and that the effect of dietary SBO on the NE of corn is influenced by the BW of pigs.

MATERIALS AND METHODS

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

Animals, Housing, and Experimental Design

Forty-eight growing and 48 finishing barrows that were the offspring of line 337 sires mated to C-22 females (PIC, Hendersonville, TN) were used. The average initial BW of the growing pigs was 27.3 ± 2.5 kg and the average initial BW of the finishing pigs was 86.0 ± 3.0 kg. All growing and finishing pigs used in the current experiment were selected based on BW and ADG during a 2-wk pre-experimental period when all pigs were fed a corn–soybean meal based diet. Within each stage of growth, pigs were allotted to an initial slaughter group (n = 16) or 4 dietary treatments (n = 8). Principles for pig allotments were similar to those described by Kil et al. (2011). All pigs were individually housed in 0.9 by 1.8 m pens equipped with a feeder, a nipple waterer, and a fully slatted concrete floor in an environmentally controlled building at the University of Illinois Swine Research Center. The room has a heater and a negative pressure ventilation system. Average room temperature was 23°C for growing pigs and 19°C for finishing pigs. The experimental period was 28 d for growing pigs and 35 d for finishing pigs. At the conclusion of the experiment, all pigs were harvested.

Table 1. Chemical and physical characteristics of corn used in this experiment (as-fed basis)

Composition	Corn
DM, %	85.90
GE, Mcal/kg	3.85
CP, %	8.54
Acid hydrolyzed ether extract, %	4.20
Crude fiber, %	1.57
Total starch,[1] %	64.20
Ash, %	1.32
Particle size,[2] µm	736

[1]Total starch was measured by the method of EEC (1999).

[2]Particle size was determined using American Society of Agricultural Engineers procedures (ASAE, 1983).

Dietary Treatments

Commercial corn (Table 1) was obtained locally and the same batch of corn was used to formulate all diets for both growing and finishing pigs. Four diets for growing pigs and 4 diets for finishing pigs were prepared (Table 2). A low-lipid basal diet containing corn, soybean meal, and no added lipids and a high-lipid basal diet containing corn, soybean meal, and 8% SBO (as-fed basis) were formulated within each stage of growth. Two additional diets were formulated by mixing 25% corn and 75% of the low-lipid basal diet (as-fed basis) or 25% corn and 75% of the high-lipid basal diet (as-fed basis). Chromic oxide (0.40%) was included as an inert marker in both low-lipid and high-lipid basal diets. A vitamin premix and a trace mineral premix were included in both basal diets to exceed the estimated nutrient requirements for pigs at each stage of growth (NRC, 1998). Because the substitution procedure was used to formulate the diets with supplemental corn, concentrations of AA, vitamins, and minerals were less in these diets than in the diets without supplemental corn. However, in formulating the diets, it was made sure that the diets with supplemental corn contained AA, vitamins, and minerals in quantities that exceeded requirements for growing and finishing pigs, respectively (NRC, 1998). As a consequence, the diets that did not contain supplemental corn were formulated to contain AA, vitamins, and minerals in excess of requirements. 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.

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

	Growing pigs				Finishing pigs			
Diets[1]:	LLB	LLC	HLB	HLC	LLB	LLC	HLB	HLC
Ingredient, %								
Ground corn	65.61	74.21	55.53	66.65	85.32	88.99	75.04	81.28
Soybean meal, 47.5% CP	28.11	21.08	30.27	22.70	9.85	7.39	12.25	9.19
Soybean oil	–	–	8.00	6.00	–	–	8.00	6.00
Dicalcium phosphate	1.95	1.46	1.95	1.46	1.34	1.01	1.35	1.01
Ground limestone	1.00	0.75	1.00	0.75	0.74	0.55	0.72	0.54
L-Lys HCl	0.60	0.45	0.55	0.42	0.51	0.38	0.45	0.34
DL-Met	0.17	0.13	0.17	0.13	0.04	0.03	0.04	0.03
L-Thr	0.26	0.19	0.26	0.19	0.14	0.11	0.14	0.10
L-Trp	0.07	0.05	0.06	0.04	0.05	0.04	0.04	0.03
L-Val	0.06	0.05	0.06	0.04	0.02	0.02	0.01	0.01
L-Ile	–	–	–	–	0.04	0.03	0.02	0.01
Salt	0.12	0.09	0.12	0.09	0.12	0.09	0.12	0.09
Mineral premix[2]	0.47	0.35	0.47	0.35	0.47	0.35	0.47	0.35
Sodium bicarbonate	0.73	0.55	0.73	0.55	0.59	0.44	0.59	0.44
Potassium carbonate	0.31	0.23	0.31	0.23	0.24	0.18	0.24	0.18
Cr_2O_3	0.40	0.30	0.40	0.30	0.40	0.30	0.40	0.30
Vitamin premix[3]	0.13	0.10	0.13	0.10	0.13	0.10	0.13	0.10
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Energy and nutrients[4]								
GE, Mcal/kg	3.81	3.79	4.21	4.15	3.79	3.78	4.12	4.10
ME, Mcal/kg	3.19	3.25	3.59	3.55	3.25	3.29	3.65	3.59
DM, %	87.67	86.98	89.07	88.23	87.24	86.76	88.05	88.07
CP, %	20.43	17.54	20.20	17.08	12.09	11.36	12.31	11.67
Lys, %	1.48	1.18	1.48	1.18	0.91	0.75	0.91	0.75
Total Starch, %	43.20	48.20	38.70	45.70	56.80	57.90	50.90	55.40
Ether extract, %	2.17	2.42	8.65	7.10	1.94	2.24	8.17	7.60
AEE,[5] %	4.03	4.31	9.93	8.70	4.36	4.26	10.77	8.88
Crude fiber, %	2.05	1.92	1.90	1.83	1.61	1.55	1.58	1.51
Ash, %	5.92	4.90	6.64	5.09	4.82	3.85	4.92	4.12
Ca, %	0.90	0.68	0.90	0.68	0.62	0.47	0.62	0.47
Bioavailable P, %	0.43	0.33	0.43	0.33	0.30	0.23	0.30	0.23

[1]LLB = basal diet containing no added lipids; LLC = 75% LLB + 25% corn; HLB = basal diet containing 8% soybean oil; HLC = 75% HLB + 25% corn.

[2]Mineral premix provided the following quantities of mineral per kilogram of basal diet: Fe, 121 mg ($FeSO_4$ H_2O); Zn, 134 mg (ZnO); Mn, 27 mg (MnO); Cu, 11 mg ($CuSO_4{\cdot}H_2O$); I, 0.47 mg (CaI_2); Se, 0.40 mg (Na_2SeO_3); and NaCl, 4.0 g.

[3]Vitamin premix provided the following quantities of vitamins per kilogram of basal diet: vitamin A as retinyl acetate, 8,590 IU; vitamin D as cholecalciferol, 884 IU; DL-α-tocopheryl acetate, 114 mg; menadione sodium bisulfite complex, 5 mg; riboflavin, 12 mg; vitamin B_{12}, 46 µg; D-Ca-pantothenic acid, 31 mg; niacin, 43 mg; and choline chloride, 421 mg.

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

[5]AEE = acid hydrolyzed ether extract.

Sample Collection and Chemical Analyses

Fresh fecal samples were collected from each pig on d 7 of each week by grab sampling and then stored at –20°C. Frozen fecal samples were pooled within each pig at the conclusion of the experiment, lyophilized, and finely ground for chemical analyses.

The comparative slaughter procedure was used to calculate retention of energy, protein, and lipids (de Goey and Ewan, 1975). Slaughter procedures and carcass measurements have been described in detail by Kil (2008) and Kil et al. (2011). Briefly, pigs were euthanized by captive-bolt stunning followed by exsanguination. Care was taken to ensure that all blood was collected from each pig and subsamples were collected. The carcass was split down the midline from the groin to the chest cavity and the viscera were removed. Empty carcasses were ground and mixed, and subsamples for chemical analyses were collected. The digestive tract was flushed with water to remove digesta. The emptied tract was combined with other organs including the liver, kidney, spleen, and lungs, and they were ground together to obtain subsamples. All subsamples of carcass, viscera, and blood were lyophilized before chemical analyses. The chemical composition of diets, feces, and body components were analyzed as previously reported (Kil et al., 2011).

Table 3. Effects of added soybean oil (SBO) and stage of growth on growth performance and apparent total tract digestibility (ATTD) of energy and nutrients in diets fed to growing or finishing pigs[1]

Stage of growth:	Growing pigs		Finishing pigs			*P*-value[2]		
Item	0% SBO	8% SBO	0% SBO	8% SBO	SEM	SBO	Stage of growth	Interaction
Initial BW, kg	27.31	27.31	85.31	86.21	1.11	0.672	<0.001	0.672
Final BW, kg	54.31	55.94	129.31	133.71	2.14	0.150	<0.001	0.500
ADG, kg	0.964	1.022	1.257	1.357	0.051	0.116	<0.001	0.671
ADFI, kg	2.064	2.194	3.887	3.800	0.125	0.860	<0.001	0.371
G:F, kg/kg	0.468	0.467	0.325	0.356	0.012	0.185	<0.001	0.165
ATTD, CP, %	77.2	76.2	74.2	76.4	1.3	0.622	0.270	0.204
ATTD, AEE,[3] %	47.5	70.1	42.9	67.9	1.1	<0.01	0.003	0.266
ATTD, GE, %	80.9	81.9	82.4	84.3	0.7	0.044	<0.001	0.518
DE of diet, kcal/kg	3,067	3,394	3,134	3,455	30	<0.001	0.031	0.919
DE of corn, kcal/kg	2,777	2,854	3,043	3,098	121	0.556	0.031	0.920

[1]Data for growing pigs are least squares means of 8 observations per treatment; data for finishing pigs are least squares means of 8 observations for pigs fed the diets containing no added SBO and of 7 observations for pigs fed the diets containing added SBO.

[2]*P*-values for main effects of added SBO and stage of growth and for their interaction.

[3]AEE = acid hydrolyzed ether extract.

Calculations

The ADG, ADFI, and G:F within each treatment and each stage of growth were calculated based on the BW of pigs and feed intake that were recorded weekly after the start of the experiment. The apparent total tract digestibility (**ATTD**) of energy, CP, and acid hydrolyzed ether extract (**AEE**) in all diets was calculated based on the concentrations of chromium in diets and feces (Chastanet et al., 2007).

The total quantity of energy, protein, and lipids in the empty body of each pig in both the initial slaughter group and dietary treatment groups was calculated from the sum of the energy, protein, and lipids in the blood, viscera, and carcass (Kil et al., 2011). The difference between the initial quantity of energy, protein, and lipids that were determined from the initial slaughter group, and the final quantity of energy, protein, and lipids that were determined from pigs fed the treatment diets was considered the total quantity of energy, protein, and lipid retentions during the entire experimental period (Oresanya et al., 2008). Energy retention was also calculated by multiplying protein gain and lipid gain by 5.66 and 9.46 kcal/g, respectively (Ewan, 2001).

The NE value for each diet was calculated from the sum of energy retention and the total quantity of the energy used for NEm (Ewan, 2001). The daily NEm 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., 1994a). The total NEm was calculated by multiplying the calculated daily NEm for each pig by the number of days pigs were fed the experimental diets (i.e., 28 d for growing pigs and 35 d for finishing pigs). The NE of supplemental corn was subsequently calculated using the difference procedure (de Goey and Ewan, 1975).

Statistical Analyses

All data were analyzed using the MIXED procedure (SAS Inst. Inc., Cary, NC) with the individual pig as the experimental unit. The UNIVARIATE procedure of SAS was used to check normal distribution of model residuals and equal variances. The residual vs. the predicted plot procedure in SAS was used to identify outliers. The model included the effect of addition of SBO, stage of growth, and their interaction for all measurements. The LSMEANS procedure was used to calculate mean values. An α-value of 0.05 was used to assess significance among means whereas $0.05 \leq P < 0.10$ was considered a tendency.

RESULTS

Pig Growth Performance and Digestibility of Energy and Nutrients

One finishing pig fed the diet containing added SBO and supplemental corn became sick and had to be removed from the experiment. All other pigs remained healthy throughout the experiment. Overall, there was no interaction between addition of SBO and stage of growth for pig growth performance and ATTD of CP, AEE, and GE (Table 3). Addition of SBO had no effect on final BW, ADG, ADFI, and G:F in growing and finishing pigs. The ATTD of AEE and GE was greater ($P < 0.05$) for the diets containing SBO than for the diets containing no SBO. Addition of SBO increased ($P < 0.01$) DE of diets ,but did not affect DE of corn. Finishing pigs had greater ($P < 0.01$) ADG and ADFI, but less ($P < 0.01$) G:F than growing pigs. The ATTD of AEE in diets was less ($P < 0.01$) for finishing pigs than for growing pigs, whereas the ATTD of GE in diets was greater ($P < 0.01$) for finishing pigs than for growing

Table 4. Effects of added soybean oil (SBO) and stage of growth on carcass composition and retention of energy, protein, and lipids in growing or finishing pigs [1]

	Growing pigs			Finishing pigs				*P*-value[2]		
Item	ISG[3]	0% SBO	8% SBO	ISG	0% SBO	8% SBO	SEM	SBO	Stage of growth	Interaction
BW, kg	26.7	51.5	53.3	84.0	125.6	130.0	2.0	0.112	<0.001	0.489
HCW, kg	21.2	41.9	43.3	71.4	105.2	109.0	2.0	0.177	<0.001	0.524
Dressing percentage, %	79.4	81.4	81.3	84.9	83.7	83.8	0.5	0.980	<0.001	0.847
Carcass composition										
DF BW,[4] kg	25.5	49.5	51.3	81.4	124.4	128.9	2.0	0.116	<0.001	0.473
DF BW, kg DM	7.5	16.8	18.6	33.4	58.3	60.3	1.3	0.136	<0.001	0.927
Total protein, kg/pig	4.4	8.5	8.5	13.4	19.5	19.6	0.4	0.865	<0.001	0.925
Total lipids, kg/pig	2.1	6.2	7.3	16.7	33.9	34.3	1.1	0.472	<0.001	0.768
Total energy, Mcal/pig	44.3	107.2	120.5	230.7	428.5	444.6	10.6	0.156	<0.001	0.891
Retention										
Protein gain, g/d	–	143.3	146.5	–	174.1	173.1	13.4	0.930	0.033	0.871
Lipid gain, g/d	–	143.2	182.4	–	506.3	511.0	31.2	0.465	<0.001	0.566
Lipid:protein,[5] g/g	–	1.0	1.3	–	3.0	3.1	0.3	0.458	<0.001	0.755
MER,[6] Mcal/d	–	2.3	2.7	–	5.8	6.2	0.3	0.135	<0.001	0.875
CER,[7] Mcal/d	–	2.2	2.6	–	5.8	5.8	0.3	0.461	<0.001	0.548

[1]Data for growing pigs are least squares means of 8 observations per treatment; data for finishing pigs are least squares means of 8 observations for pigs fed the diets containing no added SBO and of 7 observations for pigs fed the diets containing added SBO.

[2]*P*-values for main effects of added SBO and stage of growth and for their interaction.

[3]ISG = initial slaughter group (n = 16).

[4]DF BW = digesta-free BW, which is the sum of the weight of the chilled carcass, empty viscera, and blood.

[5]Lipid:protein = the ratio of daily lipid gain to daily protein gain.

[6]MER = measured energy retention.

[7]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).

pigs. The DE of diets and corn was also greater (P < 0.05) for finishing pigs than for growing pigs.

Carcass Composition and Retention of Energy, Protein, and Lipids

Addition of SBO had no effect on HCW, dressing percentage, carcass compositions, or retention of protein, lipids, and energy in growing and finishing pigs (Table 4). Finishing pigs had greater (P < 0.05) HCW, dressing percentage, digesta-free BW, total protein, total lipids, total energy, and retention of protein, lipids, and energy than growing pigs. No interactions for carcass composition and retention of energy, protein, and lipids were observed between addition of SBO and stage of growth.

Net Energy of Diets and Corn

Addition of SBO had no effects on final body energy, energy retention, and total NE intake (Table 5). Addition of SBO increased (P < 0.05) the NE of diets, but did not influence the NE:DE in diets. Addition of SBO had no influence on the NE of corn or the NE:DE in corn.

Finishing pigs had greater (P < 0.01) final body energy, energy retention, total NEm, and total NE intake than growing pigs. Diets fed to finishing pigs had greater (P < 0.01) NE values and NE:DE ratio than diets fed to growing pigs. The NE of corn was greater (P < 0.05) for finishing pigs than for growing pigs, but NE:DE in corn did not differ between growing and finishing pigs. No interaction between addition of SBO and stage of growth was observed for the NE of diets and corn.

DISCUSSION

Pig Growth Performance and Digestibility of Energy and Nutrients

As dietary SBO increased in the diets, the concentration of corn was reduced. This resulted in dietary starch being exchanged for unsaturated lipids, which presumably also reduced the absorption of glucose and increased the absorption of unsaturated fatty acids. Addition of 5 or 10% SBO to diets may improve feed efficiency of growing and finishing pigs (Benz et al., 2011; Kil et al., 2011). In this experiment, however, addition of 8% SBO did not influence feed efficiency of growing or finishing pigs. The reason for this contrasting observation is not clear. It is, however, possible that energy retention from unsaturated lipids, which dominate in SBO, is less than from saturated lipids because unsaturated fatty acids may increase NEm compared with SFA (Kil et al., 2011). Greater ADG and ADFI for finishing pigs than for growing pigs were expected because of increased capacity

Table 5. Effects of added soybean oil (SBO) and stage of growth on net energy of diets and supplemental corn fed to growing or finishing pigs[1]

Stage of growth:	Growing pigs		Finishing pigs			*P*-value[2]		
Item	0% SBO	8% SBO	0% SBO	8% SBO	SEM	SBO	Stage of growth	Interaction
Initial body energy, Mcal	44.3	44.3	225.1	228.4	3.3	0.610	<0.001	0.610
Final body energy, Mcal	107.2	120.5	428.5	444.6	10.6	0.156	<0.001	0.891
Energy retention, Mcal	62.9	76.2	203.4	216.2	9.6	0.165	<0.001	0.981
Total NEm,[3] Mcal	45.1	45.7	103.7	105.0	1.0	0.323	<0.001	0.672
Total NE intake,[4] Mcal	108.0	121.8	307.1	321.3	10.1	0.155	<0.001	0.985
Total feed intake, kg	57.8	61.4	136.1	133.0	4.2	0.941	<0.001	0.407
NE of diets, kcal/kg	1,870	1,975	2,265	2,416	61	0.036	<0.001	0.695
DE of diets, kcal/kg	3,067	3,394	3,134	3,455	30	<0.001	0.031	0.919
NE:DE in diets	0.61	0.58	0.70	0.70	0.02	0.401	<0.001	0.433
NE of corn,[5] kcal/kg	1,860	1,699	2,275	2,340	235	0.826	0.022	0.604
DE of corn, kcal/kg	2,777	2,854	3,043	3,098	121	0.556	0.031	0.920
NE:DE in corn	0.67	0.60	0.75	0.76	0.08	0.704	0.116	0.602

[1]Data for growing pigs are least squares means of 8 observations per treatment; data for finishing pigs are least squares means of 8 observations for pigs fed the diets containing no added SBO and of 7 observations for pigs fed the diets containing added SBO.

[2]*P*-values for main effects of added SBO and stage of growth and for their interaction.

[3]Total NEm was calculated by multiplying the mean metabolic BW ($kg^{0.6}$) of each pig by 179 kcal for growing and finishing pigs (Noblet et al., 1994a) and the number of days on experiment (28 d for growing pigs and 35 d for finishing pigs; Kil et al., 2011).

[4]Total NE intake = energy retention plus total NEm.

[5]NE of supplemental corn in the diet containing no added SBO and in the diet containing added SBO. The NE of corn was calculated using the difference method by subtracting the NE contribution from each basal diet containing 0 or 8% soybean oil from the NE of the diets containing 25% supplemental corn (de Goey and Ewan, 1975).

for feed consumption by finishing pigs. The reduced G:F for finishing pigs compared with growing pigs is likely a consequence of finishing pigs having greater NEm and greater lipid deposition, which decreases feed efficiency (de Lange et al., 2001).

The increased ATTD of energy in diets by addition of SBO is a consequence of a greater digestibility of energy in SBO than of energy in corn and soybean meal. It is also possible that addition of SBO contributed to a reduced rate of gastric emptying (Gentilcore et al., 2006) and a reduced passage rate for digesta (Valaja and Silijander-Rasi, 2001), which may also have contributed to the increased digestibility of energy. The greater ATTD of energy and DE of diets for finishing pigs than for growing pigs agree with previous data (Noblet and Shi, 1994) and is likely a result of greater hindgut fermentation and increased retention time of digesta in the intestinal tract of finishing pigs compared with growing pigs (Noblet and van Milgen, 2004). The increase in the ATTD of AEE in the diets with addition of SBO was expected because lipids from added oil are more digestible than intact lipids in feed ingredients (Kil et al., 2010), and the negative influence of endogenous losses on the ATTD of lipids is greater at low levels than at high levels of dietary lipids (Jørgensen et al., 1993).

Carcass Composition and Retention of Energy, Protein, and Lipids

The values for protein gain for growing pigs (143 g/d) and finishing pigs (174.1 g/d) fed the diets containing no added SBO are close to the values for growing and finishing pigs fed a similar diet in a previous experiment conducted under similar conditions (Kil, 2008). The current observation that addition of SBO did not influence lipid gain and lipid gain:protein gain is in contrast to our previous results that addition of 5 or 10% SBO increased lipid gain and lipid gain:protein gain in growing and finishing pigs (Kil et al., 2011).

Net Energy of Diets and Corn

The values for the NE of diets for growing and finishing pigs that were calculated in this experiment are less than the values that may be calculated from the NE of each ingredient published by Sauvant et al. (2004). A similar observation was made in our previous experiment, in which we determined the NE of diets containing soybean oil or choice white grease (Kil et al., 2011). The reason for this difference may be that energy retention measured by indirect calorimetry, which was used by Sauvant et al. (2004), tends to be greater than energy retention determined by the comparative slaughter method that was used in this experiment (Quiniou et al., 1995; Reynolds, 2000). Pigs used in this experiment were also allowed ad libitum access to feed whereas the values published by Sauvant et al. (2004) were obtained from pigs that were not allowed ad libitum access to feed. Pigs that have ad libitum access to feed have a reduced ATTD of energy compared with the ATTD of energy in pigs that are restricted in their feed intake (Chastanet et al., 2007), which will result in a reduced NE value of the diet. In addition, pigs that were used to determine the NE values reported by Sauvant et al. (2004) were housed in respiratory chambers whereas pigs used in this experiment were housed in a more practical facility, which may have increased the NEm of pigs and, therefore, reduced the calculated NE of the diets (Bray et al., 1997; Verstegen, 2001). Differences in pig genetics, which may have an effect on maintenance, growth, and body composition, also may result in variations in the NE of diets and ingredients among experiments (Boisen and Verstegen, 1998).

An increased NE of diets with increasing levels of dietary lipids has been reported (Just, 1982; Kil et al., 2011) and this result is primarily attributed to a greater NE value of lipids than of corn and soybean meal. Addition of lipids to the diet may also increase the digestibility of energy and AA (Cervantes-Pahm and Stein, 2008; Kil and Stein, 2011) and may increase the amount of energy absorbed in the small intestine and decrease the amount of energy absorbed in the hindgut of pigs (Just, 1982; Noblet et al., 1994a). This may influence energy use because the efficiency of energy absorbed in the hindgut is less than that of energy absorbed in the small intestine (Just, 1982; Noblet et al., 1994a). It was surprising, however, that the NE of supplemental corn was not affected by the addition of SBO to the diets because the energetic efficiency of starch is less for ATP synthesis (68%) than for de novo lipogenesis (74 to 84%, Black, 1995; Van Milgen et al., 2001). In the diets containing SBO, it was expected that dietary lipids would be used primarily for body lipid deposition and, therefore, increase the use of starch in corn for ATP synthesis rather than for de novo lipogenesis, relative to the diets containing no SBO. Therefore, the addition of SBO was expected to reduce the NE of corn. The reason such an effect was not observed may be that addition of lipids increases the digestibility of energy and nutrients in the diet (Cervantes-Pahm and Stein, 2008; Kil and Stein, 2011), possibly by reducing gastric emptying (Gentilcore et al., 2006) and the passage rate of digesta (Valaja and Silijander-Rasi, 2001), which may compensate for the reduction in the NE value for corn by dietary SBO. In addition, the difference in the theoretical efficiency of using starch in corn between ATP synthesis and de novo lipogenesis may be too small to be detected in an experiment using live animals.

The greater NE of supplemental corn for finishing pigs than for growing pigs is in agreement with Noblet et al. (1994b) who reported that the NE of cornstarch for pigs at 100 kg was greater than for pigs at 45 kg. The reason for this observation may be that in finishing pigs, more starch is used for de novo lipogenesis than in growing pigs because finishing pigs have a greater potential for lipid gain than growing pigs (Leat, 1983; de Greef et al., 1994). Sows also have greater DE and ME values of most feed ingredients compared with growing pigs (Fernandez et al., 1986; Le Goff and Noblet, 2001; Cozannet et al., 2010), which further indicates that energy use is impacted by pig BW. It is also possible that the difference between growing and finishing pigs in the calculated values for NE of corn is a result of the fact that the same value for NEm was used for both groups of pigs. It is possible that growing pigs have a greater NEm than finishing pigs and if that is the case, then that would reduce the difference between growing and finishing pigs in calculated NE values. However, as separate values for NEm for growing and finishing pigs are lacking, we used the same value for both groups of pigs as has also been practiced in previous experiments in which pigs with different BW were used (Noblet et al., 1994b). Nevertheless, based on calculations using the same NEm for both groups of pigs, results of the experiment indicate that the energy in corn and SBO is more efficiently used by finishing pigs than by growing pigs. There was no interaction for the NE of corn between added SBO and stage of growth, which indicates that the difference in the NE value for corn between growing pigs and finishing pigs is unaffected by the concentrations of SBO in the diets.

In conclusion, results from this experiment indicate that addition of SBO increases the NE of diets, but has no influence on the NE of corn. Results also indicate that SBO has no effect on growth performance, carcass composition, or retention of energy, protein, and lipids in growing and finishing pigs. Diets fed to finishing pigs had greater DE and NE concentrations than diets fed to growing pigs. Likewise, the NE of corn is greater for finishing pigs than for growing pigs, but effects of stage of growth on the NE of diets and corn are not influenced by dietary SBO.

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