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Response to dietary digestible energy concentration in growing pigs fed cereal grain-based diets[1]

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ABSTRACT: Understanding how energy is utilized by the pig, and how the pig responds to changes in dietary energy concentration, is essential information in determining the optimal concentration of dietary energy under farm conditions, which are often highly diverse. The objective of these experiments was to determine how changes in dietary DE concentration, achieved through graded changes in diet composition, would affect the performance and carcass composition of growing pigs. In Exp. 1, which was conducted in a research facility, 300 pigs (31.1 ± 2.6 kg) were assigned to diets containing 3.09, 3.24, 3.34, 3.42, or 3.57 Mcal of DE/kg. Experiment 2, which was conducted at a commercial swine farm, involved 720 pigs (36.8 ± 5.9 kg) assigned to diets containing 3.12, 3.30, or 3.43 Mcal of DE/kg. Increased DE concentration was attained by using more wheat, soybean meal, and fat and less barley; true ileal lysine was adjusted as DE increased, and minimal AA:lysine ratios were maintained. In Exp. 1, ADG improved linearly as the energy content of the diet increased ($P = 0.03$). Feed intake decreased ($P < 0.001$) and feed efficiency and daily caloric intake improved ($P = 0.005$) with increased DE content. Variability in growth was not affected by treatment. Carcass index and LM thickness were not affected by increasing dietary DE content; backfat thickness, however, was increased ($P < 0.001$). In Exp. 2, overall ADG was unaffected by dietary energy content, although an improvement in growth was observed until the pigs reached approximately 80 kg of BW. Overall feed intake decreased with increasing energy content ($P = 0.01$), although this was not observed during the initial 6 wk of the experiment. Carcass index, lean yield, and backfat were not affected by increasing dietary energy content, whereas LM thickness tended to increase ($P = 0.08$). The value per pig was unaffected by increasing dietary energy content in both experiments, and returns above feed costs were reduced. Increasing the energy density of the diet for growing pigs through incremental changes in dietary composition had a variable impact on overall growth performance and carcass quality. Increasing the dietary DE had no effect on variations in BW at the time of marketing.

Key words: canola oil, dietary energy, digestible energy, swine, tallow

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INTRODUCTION

Energy is expected to become an increasingly expensive nutrient as competition with biofuel industries grows for ingredients rich in starch or oil. Understanding how energy is utilized by the pig, and how the pig responds to changes in dietary energy concentration, is essential information in determining the optimal concentration of dietary energy under farm conditions, which are often highly diverse.

It has generally been assumed that over a wide range of dietary energy concentrations, growing pigs will adjust feed intake to maintain a constant or nearly constant daily energy intake (Ellis and Augspurger, 2001). Unfortunately, this range of energy is poorly defined. King (1999) suggested that performance in growing pigs would not be impaired at dietary DE concentrations above 3,465 kcal/kg, whereas the NRC (1998) concluded that daily energy intake would be constant, provided pigs had access to feed ad libitum. Campbell and Dunkin (1990) reported that the capacity of the

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pig for growth exceeded its ability to consume sufficient energy between 20 and 50 kg, but this limitation in energy intake was removed in heavier animals. Black (1995) suggested that the critical lower limits would be 3,760, 3,290, and 2,350 kcal of DE/kg for pigs weighing less than 20 kg, between 20 to 50 kg, and greater than 50 kg, respectively. Clearly, there is little agreement in the literature on the capacity of the pig to optimize or maximize daily energy intake when offered feed ad libitum.

Energy is a challenging subject to study. Changes in energy concentration inevitably lead to changes in ingredients, making it difficult to distinguish ingredient effects from energy effects. Studies investigating energy are also confounded by feed intake, which in turn is affected by genotype, health status, the physical environment, diet palatability, and prior nutritional history (Bikker and Verstegen, 1994; Nyachoti et al., 2004). The objective of the 2 experiments was to determine how changes in dietary DE concentration, achieved through graded changes in diet composition, would affect the performance and carcass composition of growing pigs.

MATERIALS AND METHODS

All animal protocols and procedures were approved by the University of Saskatchewan Committee on Animal Care and Supply for adherence to guidelines established by the Canadian Council on Animal Care (1993). Experiment 1 was carried out at a commercial research facility (PSC Elstow Research Farm, Saskatoon, Saskatchewan, Canada), whereas Exp. 2 was conducted at a commercial swine farm located in central Saskatchewan.

Exp. 1

Treatment and Diets. The experiment was conducted using a randomized complete block design with 3 replicates (rooms) and 5 treatments, consisting of formulated DE concentrations of 3.05, 3.19, 3.33, 3.47, and 3.61 Mcal/kg. Thus, diets with a relatively low energy concentration were included to challenge the ability of the pig to consume sufficient energy to maximize growth rate (Black, 1995; King, 1999). The diets, fed as a mash, were formulated by using wheat, barley, soybean meal, and canola meal as the main ingredients. Increasing energy concentration was attained by decreasing the proportion of low-energy ingredients (barley and canola meal) while increasing the proportions of high-energy ingredients (wheat, soybean meal, and canola oil). Although it is impossible to study energy concentration without altering the ingredient composition of the diet, this gradual change in ingredient proportions was adopted to minimize the impact of specific ingredient effects. At the same time, diet compositions that would be reflective of those used in commercial practice over the range of energy concentrations were used in the study. Celite (0.4%; Celite Corp., Lompoc, CA) was added as a source of AIA to allow determination of the actual DE content of the diets. Diets were formulated to meet or exceed nutrient requirements (NRC, 1998) for male and female pigs (25 to 50, 50 to 80, and 80 to 120 kg).

The diets within each phase differed in the true ileal digestible (**TID**) lysine:DE ratio. For barrows, the TID lysine:DE ratios were 2.9, 2.5, and 2.0 g/Mcal for 25 to 50, 50 to 80, and 80 to 120 kg, respectively. For gilts, the TID lysine:DE ratios were 3.0, 2.6, and 2.1 g/Mcal of DE for these same BW ranges. Other AA were balanced with lysine according to ideal AA ratios (NRC, 1998). Diet composition for the low- and high-energy male diets is presented in Table 1. The composition of intermediate-energy diets was proportional to the high- and low-energy basal diets; diets for gilts were similar to those for barrows, but with an increased AA content as described previously.

Animals and Facilities. The first experiment was conducted at the Prairie Swine Centre, using 3 all-in, all-out rooms, each containing 20 pens divided equally between barrows and gilts, with 5 pigs per pen. Each pen measured 2.36 × 1.68 m, had fully slatted floors, and was equipped with automatic lighting (12 h light:12 h dark) and integrated controllers regulating heating and ventilation. A single-space dry feeder and a single nipple drinker were provided in each pen. Pens within a room were randomly assigned to treatments. One room was filled each week and represented the outcome from farrowings from 1 wk. The initial temperature was set at 23°C and was programmed to decrease to 15°C over 10 wk.

A total of 150 barrows and 150 gilts (C22 female × 337 male; PIC Canada Ltd., Winnipeg, Manitoba, Canada) with an average initial BW of 31.1 ± 2.6 kg were selected and assigned over 3 wk to 1 of the 5 dietary treatments when they left the nursery at 8 wk of age. This resulted in 6 pens and 30 pigs$\cdot$sex$^{-1}\cdot$treatment^{-1}. Pigs were selected for inclusion in the experiment on the basis of BW to provide light and heavy blocks. Pigs with extreme BW per day-of-age values within each BW block were not used. The objective of the selection process was to provide uniform blocks of animals within each BW range.

Data and Sample Collection. Pigs were weighed individually at the beginning and end of each phase. Additionally, all pigs within a BW block were weighed when the first pig was marketed to determine variation in BW. Pigs were marketed individually when they reached a minimum of 113 kg within the week of shipping (Mitchell's Gourmet Foods Inc., Saskatoon, Saskatchewan, Canada). Those pigs not reaching 113 kg during the experimental period were marketed as a group 5 wk after the first pig within a block was marketed. Carcass weight (head on), backfat thickness, LM thickness, and estimated percentage of lean yield were collected at slaughter and the carcass index was calculated, all according to the Canadian Hog Carcass Grad-

Table 1. Ingredient and nutrient composition of the diets formulated to contain 3.05 and 3.61 Mcal of DE/kg and fed to the male pigs in Exp. 1 (as-fed basis)[1]

	Phase I		Phase II		Phase III	
Item	3.05	3.61	3.05	3.61	3.05	3.61
Ingredient, %						
Barley	77.708	19.600	83.289	—	86.390	—
Soybean meal, 46% CP	12.900	23.600	12.200	21.000	10.400	16.400
Wheat	—	46.319	—	69.700	—	74.820
Canola meal	5.000	—	—	—	—	—
Canola oil	—	5.800	—	4.800	—	5.000
Dicalcium phosphate	1.200	1.350	1.400	1.400	0.700	0.950
Limestone	0.800	0.850	0.800	0.850	0.500	0.800
PSCI mineral[2]	0.500	0.500	0.500	0.500	0.500	0.500
PSCI vitamin[3]	0.500	0.500	0.500	0.500	0.500	0.500
Salt	0.500	0.500	0.500	0.500	0.500	0.500
Lysine·HCl	0.284	0.290	0.245	0.200	0.100	0.100
Threonine	0.115	0.155	0.095	0.095	0.010	0.025
Methionine	0.080	0.135	0.065	0.055	—	0.005
Tryptophan	0.013	0.001	0.006	—	—	—
Celite[4]	0.400	0.400	0.400	0.400	0.400	0.400
Calculated composition						
DE, Mcal/kg	3.05	3.61	3.05	3.61	3.05	3.61
TID Lys,[5] g/Mcal of DE	2.90	2.90	2.50	2.50	2.00	2.00
Ca, %	0.76	0.76	0.77	0.75	0.65	0.65
P (total), %	0.65	0.65	0.65	0.65	0.55	0.55

[1] Other energy concentrations were intermediate. Diets for female pigs were formulated to contain 0.1 g additional lysine per Mcal of DE.

[2] PSCI = Prairie Swine Centre Inc. Provides per kilogram of diet: 80 mg of Fe as ferrous sulfate, 100 mg of Zn as zinc sulfate, 25 mg of Mn as manganous oxide, 50 mg of Cu as copper sulfate, 0.5 mg of I as ethylenediamine dihydroiodide and 0.1 mg of Se as sodium selenite.

[3] Provides per kilogram of diet: 8,250 IU of vitamin A, 825 IU of vitamin D_3, 40 IU of vitamin E, 4 IU of vitamin K_3, 250 μg of vitamin B_{12}, 5 mg of riboflavin, 15 mg of pantothenic acid, 35 mg of niacin, 2 mg of folacin, 1 mg of thiamine, and 200 μg of biotin.

[4] Celite (Celite Corp., Lompoc, CA) is a diatomaceous earth product that serves as a source of added AIA.

[5] True ileal digestible lysine.

ing Settlement System (Canadian Pork Council, 1986). Dressing percentage was calculated based on carcass weight and BW at shipping.

Average daily rate and efficiency of gain, as well as ADFI, were calculated for each phase and overall. Individual BW was used to calculate the CV of BW within a pen. These values were used for the statistical evaluation of treatment effects on variability in growth. Each pen contained only 5 pigs; therefore, the CV was also calculated within treatment on a room basis.

Fecal samples were collected at the midpoint of each phase to determine the actual DE content of the experimental diets. A minimum of 1 fresh sample was collected from the floor of each pen. Feed samples were taken weekly throughout the experiment. Fecal samples were lyophilized and feed and fecal samples were composited by phase and diet, ground (1-mm screen), and analyzed for DM (AOAC, 1990), GE (IKA Bomb Calorimeter C5000, IKA Works, Wilmington, NC), and AIA (McCarthy et al., 1974).

Statistical Analysis. The pen was the experimental unit for all analyses. Performance criteria were analyzed by the MIXED procedure (SAS Inst. Inc., Cary NC). The model included the main effects of DE (measured), sex, phase, BW block, and all interactions, with phase as a repeated measure. Initial BW was used as a covariate. The appropriate covariance structure was determined for each variable based on the fit statistics provided in SAS. If a phase × treatment interaction was observed ($P < 0.05$), a separate analysis was conducted within each phase. The linear or quadratic response to the measured DE was determined by using the contrast statement. Coefficients for unequally spaced intervals were obtained through the IML procedure of SAS. Carcass criteria were analyzed by the MIXED procedure in SAS. The model included the main effects of DE (measured), sex, BW block, and interactions. Settlement weight was used as a covariate for carcass measurements. For all variables, significance was declared at $P < 0.05$ and a trend was presented where $P > 0.05$ but <0.10.

Exp. 2

Treatments and Diets. Treatments consisted of formulated dietary DE concentrations of 3.20, 3.35, or 3.50 Mcal/kg. Pigs remained on the same energy concentration throughout the experiment. Ingredient and nutrient compositions are shown in Table 2. The diets were formulated according to commercial practice. Increasing the energy content of the diet resulted in increased use of wheat, soybean meal, and tallow and in

Table 2. Ingredient and nutrient composition of experimental diets formulated to contain 3.20 and 3.50 Mcal of DE/kg in Exp. 2 (as-fed basis)[1]

	Phase I		Phase II		Phase III	
Item	3.20	3.50	3.20	3.50	3.20	3.50
Ingredient, %						
Barley	61.350	22.100	63.370	28.100	54.905	15.700
Wheat	16.420	49.350	15.410	43.815	25.180	58.150
Soybean meal, 46% CP	15.300	17.900	14.800	18.100	13.800	16.500
Meat meal	4.000	4.000	4.000	4.000	3.000	3.000
Tallow[2]	0.500	4.000	0.500	4.000	0.500	4.000
Dicalcium phosphate	0.550	0.550	0.300	0.250	0.750	0.700
Limestone	0.200	0.300	0.200	0.250	0.650	0.700
PSCI mineral[3]	0.400	0.400	0.400	0.400	0.400	0.400
PSCI vitamin[4]	0.400	0.400	0.400	0.400	0.400	0.400
Salt	0.400	0.400	0.400	0.400	0.400	0.400
Lysine·HCl	0.290	0.350	0.160	0.200	0.015	0.050
Threonine	0.075	0.110	0.010	0.035	—	—
Methionine	0.040	0.065	—	—	—	—
Oxytetracycline 200[5]	0.075	0.075	—	—	—	—
Tylan 40[6]	—	—	0.050	—	—	—
Calculated composition						
TID Lys,[7] g/Mcal of DE	3.05	3.05	2.70	2.70	2.15	2.15
Crude fat, %	2.19	5.53	2.20	5.54	2.21	5.54
Ca, %	0.69	0.71	0.66	0.65	0.81	0.80
P (total), %	0.58	0.55	0.55	0.55	0.60	0.60
Crude fat, %	2.41	5.34	1.95	4.94	1.88	4.99
CP, %	19.3	21.9	18.4	20.3	18.1	19.3

[1] Other energy concentrations were intermediate. Diets for female pigs were formulated to contain 0.1 g of additional lysine/Mcal of DE.

[2] Titer, 41.2°C; FFA (as oleic acid), 5.12%; total moisture, impurities, and unsaponifiables, 0.48%; iodine value, 52.4; peroxide value, 1.0 mEq/kg; fat stability using the active oxidation method, 15.2 mEq/kg; and Fat Analysis Committee color (AOCS, 1998), not darker than 19.

[3] PSCI = Prairie Swine Centre Inc. Provided per kilogram of diet: 64 mg of Fe as ferrous sulfate, 80 mg of Zn as zinc sulfate, 20 mg of Mn as manganous oxide, 40 mg of Cu as copper sulfate, 0.4 mg of I as ethylenediamine dihydroiodide, and 0.08 mg of Se as sodium selenite.

[4] Provided per kilogram of diet: 6,600 IU of vitamin A, 660 IU of vitamin D_3, 32 IU of vitamin E, 3.2 IU of vitamin K_3, 0.02 mg of vitamin B_{12}, 4 mg of riboflavin, 12 mg of pantothenic acid, 28 mg of niacin, 1.6 mg of folacin, 0.8 mg of thiamine, and 0.16 mg of biotin.

[5] Provided 330 g of activity of oxytetracycline·HCl (Oxy 200, Bio Agri Mix LP, Mitchell, Ontario, Canada) per metric ton. Initially, the phase 1 diets did not contain medication, but oxytetracycline was added by the third delivery as prescribed by the herd health veterinarian.

[6] Provided 44 g of activity of tylosin (Tylan 40, Elanco, Guelph, Ontario, Canada) phosphate per metric ton.

[7] True ileal digestible lysine.

less barley. Feed was provided as mash, in accordance with the standard practice of the farm. The tallow was analyzed by a commercial laboratory (SGS Canada, British Columbia, Canada) for titer, FFA, moisture, insoluble impurities, and unsaponifiable matter; for iodine and peroxide values by using AOCS methods (AOCS, 1998); and for calories by a method described by ASTM International (method 5865; ASTM, 2003).

A constant TID lysine:DE ratio was maintained across energy concentrations; thus, the concentration of lysine increased in proportion to the increase in dietary energy. Other AA were formulated to achieve a constant minimum ratio to lysine (NRC, 1998). The diets differed in TID lysine:DE ratio across phases: 3.05, 2.70, and 2.15 g of lysine/Mcal of DE for phases 1, 2, and 3, respectively. Other nutrients were formulated to meet or exceed the requirements of pigs as defined by NRC (1998).

Males remained on phase 1 diets for 4 wk, on phase 2 diets for 4 wk, and on phase 3 diets for the remainder of the experiment, or approximately 5 wk. Females remained on phase 1 diets for 6 wk, on phase 2 diets for 4 wk, and on phase 3 diets for the remainder of the experiment, or approximately 3 wk. This feeding protocol allowed an approximation of split-sex feeding within the constraint of the number of available feed bins.

Animals and Facilities. This experiment was conducted in 3 grower and 3 finisher rooms at a commercial pig farm located in central Saskatchewan. It is a single-site, 600-sow, farrow-to-finish commercial barn. Each room consisted of 12 partially slatted pens with 20 pigs per pen, providing a total of 36 pens and 720 pigs on test. Feeders, which were shared between 2 pens, were modified with an insert to allow separate feed delivery to individual pens. Adjacent pens were assigned to the same treatment diet to avoid accidental feed contamination among treatments. Temperature, ventilation, and lighting were controlled automatically and remained as set for normal operating conditions in the barn. The temperature decreased from an initial setting of 18°C to 14°C over the course of the experiment.

The smallest 15% of the pigs in this barn were removed at the end of the nursery phase to an off-site location. Therefore, experimental animals consisted of the heaviest 85% of the pigs leaving the nursery. Approximately 240 pigs/wk (36.8 ± 5.9 kg), blocked by BW within sex to attain heavy and light blocks, were assigned to each of the 3 dietary treatments. Thus, there were 6 pens or 120 pigs$\cdot$sex$^{-1}\cdot$treatment^{-1}. Pairs of pens within a room were assigned randomly to treatment. Pigs remained with the same pen mates when they were moved from the grower to the finisher room.

Data and Sample Collection. Individual BW were recorded at the beginning of the experiment and at marketing of the first pig. Total pen BW were recorded every 3 wk until the first pig within a block was marketed. Daily rate and efficiency of gain, as well as feed intake, were calculated for the total grow-out period and for each 3-wk period. Variability in BW (CV) was calculated by using individual BW at d 0 and 57 (first marketing day). As described in Exp. 1, the CV was also calculated within treatment on a room basis.

All animals were maintained on the experimental diets, and feed intake was measured until all pigs within the pen were marketed, or when nonexperimental pigs entered those pens. The normal practice in this barn was to hold back pigs from 1 finishing room that were too light to market and to place them in the following finishing room. These held-back pigs were placed in empty pens, when available, but otherwise were placed in pens with other pigs. Whenever possible, held-back pigs were placed in pens receiving the same experimental diet so that carcass information could still be collected. If animal movement required that pigs received a different diet, they were weighed, and thereafter their growth performance was no longer recorded. Regardless, once pigs were mixed with nonexperimental pigs, the recording of feed intake was terminated and carcass data were deleted from the data set.

Before marketing, pigs were tattooed with a unique pen number. Pigs were chosen for market according to the standard operating procedure of the barn; thus, any pig that weighed at least 116 kg on selection day, corresponding to a shipping BW of approximately 118 kg, was shipped (Olymel LP, Red Deer, Alberta, Canada). Carcass weight (head on), backfat thickness, LM thickness, and estimated percentage of lean yield were collected at slaughter according to the Canadian Hog Carcass Grading Settlement System (Canadian Pork Council, 1986). Dressing percentage was calculated based on dressed weight and BW at shipping.

Fecal samples were collected at the midpoint of each phase to determine actual DE content of the experimental diets. A minimum of 1 fresh sample was taken from each pen and analyzed as described in Exp. 1. Celite was not added to these diets because sufficient naturally occurring AIA was present to eliminate the need for an exogenous indigestible marker.

Statistical Analysis. The pen was the experimental unit for all analyses, and the main effects of energy, sex, BW group, and their interactions were determined by using the MIXED procedure (SAS Inst. Inc., Cary, NC). Room was considered a random effect. The initial analysis included all possible interactions. Because none of the interactions was significant for performance data ($P > 0.20$), they were removed from the model. However, some of the interactions approached significance for the carcass data ($P < 0.20$) and thus were kept in the model. Initial BW (d 0) and market BW were used as covariates for the performance and carcass data, respectively.

DE Intake

Actual DE intake (kcal/d) was calculated for both experiments by using the measured DE content of the diets and daily feed intake data. This was compared with energy intake as predicted by NRC (1998) by using the equation DE intake (kcal/d) = 13,162 × $(1 - e^{-0.0176\text{ BW}})$ as described by Ewan (1986).

RESULTS

Exp. 1

Treatment diets were formulated to increase in increments of 140 kcal of DE/kg, beginning with the low-energy diet of 3,090 kcal or 3.09 Mcal of DE/kg. This would be considered a very low-energy diet, especially for pigs weighing less than 50 kg in regions where diets are based on wheat and barley. Actual DE content was measured at the midpoint of each phase, and the results indicated that formulated DE underestimated actual DE by 40 to 50 kcal in the low- and low/medium-energy diets. The medium-energy diet (3.34 Mcal of DE/kg) was underestimated by only 6 kcal of DE/kg, and the 2 higher-energy diets (medium/high and high) were overestimated by 48 and 43 kcal of DE/kg, respectively (data not shown). Thus, overall there was a tendency for the measured DE to be greater than formulated for the low- and low/medium-energy diets, whereas the reverse was true for the medium/high- and high-energy diets. Average DE content, determined separately for males and females, showed a difference of only 10 kcal/kg; this difference attributable to sex tended to be greater in phase 1 than in phase 3 (data not shown). The measured DE content of the diets averaged 3.09, 3.24, 3.34, 3.42, and 3.57 Mcal/kg (as-fed basis).

The tallow averaged 9.24 Mcal of GE/kg, 5.12% FFA, and 0.42% moisture, insoluble impurities, and unsaponifiable matter. The iodine value was 52.4, the peroxide value was 1.0 mEq/kg, and the titer test was 41.2°C (data not shown). This confirmed that the tallow used in this study was of high quality.

The pigs began the experiment at an average BW of 31.1 ± 2.6 kg. Average daily gain improved as the energy concentration of the diet increased (linear, $P = 0.03$; Table 3). This was observed consistently across all 3 phases (phase × DE interaction, $P = 0.92$). Males grew faster ($P = 0.002$) and consumed more feed ($P < 0.001$) than females. Feed intake decreased as the energy density of the diet increased ($P < 0.001$), and this tended to become more pronounced as the pigs grew (phase × DE interaction, $P = 0.08$). Males consumed more feed than females, but there was a treatment × sex interaction ($P < 0.05$). Feed efficiency improved as the energy concentration of the diet increased (linear, $P < 0.001$). Feed efficiency was similar between males and females ($P = 0.11$); however, the decrease in G:F with increasing DE as the pigs grew tended to be more pronounced in males than in females (sex × phase interaction, $P = 0.07$).

The variability in BW (% CV), calculated from within pen BW, was unaffected by treatment. Variability in BW increased as the pigs grew ($P = 0.005$), and there was no phase × treatment interaction. The within-pen (n = 5) CV allowed for statistical analysis of

Table 3. Least squares means describing the performance of pigs consuming diets containing 3.09 to 3.57 Mcal/kg across 3 phases of growth (Exp. 1)[1]

		Diet, measured DE, Mcal/kg						*P*-value[2]		
Item	Phase	3.09	3.24	3.34	3.42	3.57	SEM	DE,[3] linear	Sex	Phase
Initial BW, kg		31.17	31.06	31.52	31.19	31.08	0.24			
Final BW, kg		115.07	115.51	115.26	115.02	115.58	0.41			
ADG, kg	1	0.95	0.97	0.98	0.98	0.99				
	2	1.05	1.08	1.10	1.07	1.08				
	3	0.99	1.00	1.01	1.00	1.04				
	Overall	1.00	1.02	1.04	1.02	1.03	0.01	0.03	0.002	0.001
ADFI, kg	1	1.95	1.95	1.90	1.89	1.87	0.04	0.04	<0.001	—
	2	2.75	2.71	2.73	2.62	2.51	0.04	<0.001	<0.001	—
	3	3.29	3.20	3.16	3.05	2.95	0.04	<0.001	<0.001	—
	Overall[4,5,6]	2.66	2.62	2.62	2.52	2.44	0.09	<0.001	<0.001	<0.001
G:F, kg/kg	1	0.49	0.50	0.52	0.52	0.53				
	2	0.38	0.40	0.40	0.41	0.43				
	3	0.30	0.32	0.32	0.33	0.36				
	Overall[7]	0.39	0.40	0.41	0.42	0.44	0.004	<0.001	0.11	<0.001
Energy intake, Mcal of DE/d	1	6.01	6.32	6.36	6.44	6.66				
	2	8.47	8.81	9.11	8.91	8.95				
	3	10.18	10.35	10.57	10.45	10.51				
	Overall[4,8]	8.22	8.49	8.76	8.61	8.71	0.10	0.003	0.001	0.001
Gain, kg/Mcal of DE intake	1	0.16	0.15	0.16	0.15	0.15				
	2	0.12	0.12	0.12	0.12	0.12				
	3	0.10	0.10	0.10	0.10	0.10				
	Overall[7]	0.13	0.12	0.12	0.12	0.12	0.001	0.01	0.10	<0.001
BW CV,[9] %	Day 0[10]	5.47	5.83	5.07	5.91	6.28	0.60	0.38	0.08	—
	1	4.99	5.57	3.76	4.99	5.38				
	2	5.16	5.92	5.51	6.01	6.46				
	3	6.01	6.94	5.87	6.09	6.32				
	Overall	5.39	6.14	5.05	5.70	6.06	0.44	0.50	0.08	0.005
Days on test	1	23.3	23.0	22.8	22.9	22.9				
	2	25.9	24.8	24.6	25.0	25.0				
	3	35.4	35.8	36.8	34.6	34.0				
	Overall	84.6	83.6	84.2	82.5	81.9	0.40	0.09	<0.001	<0.001

[1] Animals (n = 300) were put on the experiment at an initial BW of 31.1 ± 2.6 kg. Phase 1, 30 to 50 kg of BW; phase 2, 50 to 80 kg of BW; phase 3, 80 to 120 kg of BW.

[2] *P*-values for "overall" refer to the results of the analysis using phase as a repeated measure. The model includes initial BW (used as the covariate), DE, BW block, sex, phase, and all 2- and 3-way interactions. Significant interactions are indicated with superscripts; all other interactions, $P > 0.10$. *P*-values for individual phases refer to analysis on individual phases because of a significant DE × phase interaction or a tendency for a DE × phase interaction.

[3] Quadratic (ADFI, $P = 0.08$; caloric intake, $P = 0.05$; all other variables, $P > 0.10$).

[4] Sex × phase interaction ($P < 0.05$).

[5] Phase × DE interaction ($P < 0.10$).

[6] Sex × DE interaction ($P < 0.10$).

[7] Sex × phase interaction ($P < 0.10$).

[8] Sex × DE interaction ($P < 0.05$).

[9] Calculated within pen (n = 5).

[10] CV at experiment initiation; not included in the repeated measures analysis and no covariate was used. Phase 3 CV refers to pen CV at first removal of market pigs.

Table 4. Least squares means describing carcass variables and the economic value of pigs consuming diets containing 3.09 to 3.57 Mcal of DE/kg of diet (Exp. 1)

	Diet, measured DE, Mcal/kg							Sex		
Item	3.09	3.24	3.34	3.42	3.57	SEM	P-value[1]	Barrow	Gilt	P-value
Market BW, kg	115.1	115.5	115.2	115.0	115.6	0.6	0.59	115.7	114.9	0.03
Dressing %	78.1	78.0	78.6	78.8	79.0	0.2	0.001	78.5	78.6	0.42
Carcass index[2,3,4]	113.8	112.9	113.4	111.8	113.2	0.5	0.23	111.4	114.7	<0.001
Lean yield,[3,4] %	61.5	61.2	60.9	61.1	60.7	0.3	0.01	60.2	62.0	<0.001
Fat depth, mm	16.8	17.8	18.3	18.6	19.4	0.5	<0.001	20.4	16.0	<0.001
LM depth, mm	61.7	60.5	62.7	60.3	61.0	1.1	0.65	59.8	62.7	0.008
Value,[4,5] Cdn \$/pig	118.05	116.96	119.18	116.59	117.85	0.90	0.81	115.28	120.18	<0.001

[1] Statistical model included the effects of diet DE, sex, BW group, and all interactions. Market BW was used as a covariate (with the exception of market BW). P-values are for the linear effect of DE. Quadratic ($P > 0.05$).

[2] Carcass index represents the basis for establishing carcass value according to the Canadian Hog Carcass Grading Settlement System (Canadian Pork Council, 1986). For example, a pig with a carcass index of 113 will receive 1.13 times the settlement price of the packer, plus any applicable premiums.

[3] DE × sex interaction ($P < 0.05$).

[4] DE × sex × BW group phase interaction ($P < 0.05$).

[5] Index/100 × settlement weight + premiums. Prices [2004; Canadian dollars (Cdn \$)] of \$1.09 to 1.13/kg were used.

treatments. As indicated by the high SEM, there was considerable variability in these CV values. Because of the experimental design and initial selection of animals according to BW, they did not provide an accurate estimation of overall variability within a typical pig population. The average of the room CV for BW on d 0 was 10.3, 10.1, 9.7, 9.9, and 9.6% for the high- to low-energy diets, respectively. On d 14 of phase 3 (before any pigs were marketed), these values were 6.6, 7.4, 5.9, 6.5, and 5.5% for the 5 diets, respectively, indicating an overall decrease in relative variability as the pigs approached market BW.

Days on the experiment tended to decrease with increasing dietary DE concentration (linear, $P = 0.09$). Females were on test approximately 2 d longer than males (sex, $P < 0.001$). Days on test differed among phases ($P < 0.001$); however, this was expected because of the experimental design.

Increasing the energy density of the diet had no effect on either the carcass index or thickness of the LM (Table 4). The lean yield decreased as DE concentration increased (linear, $P < 0.01$), and increasing the dietary DE concentration from 3.09 to 3.57 Mcal of DE/kg resulted in an increase of more than 2.5 mm of backfat (linear, $P < 0.001$). Concurrent with the increased carcass fat was an increase in dressing percentage ($P < 0.01$). The overall price and value per pig did not differ among treatments (data not shown), although the premiums paid decreased with increasing energy density ($P < 0.05$; data not shown).

Exp. 2

Measured DE averaged 50, 57, and 74 kcal/kg (as-fed basis) less than formulated for the 3.09, 3.24, or 3.34 Mcal of DE/kg treatments, respectively (data not shown). Measured DE averaged 3.28, 3.25, and 3.24 Mcal/kg in phase 1, phase 2, and phase 3, respectively. The measured DE content of the diet averaged 3.29 Mcal/kg for females and 3.27 Mcal/kg for males.

Overall (d 0 to market) ADG was not affected by dietary energy (Table 5). Average daily gain ($P = 0.02$) improved with increased energy density of the diet during the first two 3-wk periods (d 0 to 21, d 22 to 42). Conversely, increasing the dietary DE concentration resulted in decreased overall ADFI ($P = 0.01$), although this was not apparent during the first 6 wk of the experiment. Feed efficiency improved with increasing dietary energy during the initial 6 wk of the experiment ($P < 0.01$) and overall ($P = 0.002$).

The BW CV, determined on a room basis, averaged 16% on d 0 and 12% on d 57 over the 3 treatments. No pattern attributable to treatment could be discerned (data not shown). Carcass dressing percentage (Table 6) tended to improve with increased DE content of the diet ($P = 0.07$) and was greater for females than males ($P = 0.003$). Carcass index, percentage of lean yield, and backfat were not affected by dietary energy content. Longissimus muscle thickness tended to increase with increased energy content of the diet ($P = 0.08$). Backfat was thicker in males ($P < 0.001$), whereas dressing percentage, lean yield, and LM thickness were greater in females ($P < 0.001$).

Energy Intake

In Exp. 1, despite the decrease in ADFI, caloric intake (Mcal of DE/d) increased with increasing energy concentration of the diet (linear, $P = 0.003$; Table 3). Caloric intake was greater in males than in females ($P < 0.001$) and increased as the pigs grew ($P < 0.001$). In Exp. 2, energy intake (Mcal of DE/d) improved ($P <$

0.001) with increased energy density of the diet during the first two 3-wk periods (d 0 to 21 and d 22 to 42; Table 4).

The daily intake of DE (kcal/d), as a percentage of that predicted by NRC (1998), is shown in Figure 1 for both experiments. In Exp. 1, pigs consumed less energy than predicted by NRC throughout the experimental period. Conversely, in Exp. 2, it was not until the final period (d 43 to 57; approximately 80 kg to market BW) that energy intake was equivalent to, or greater than, that predicted by the NRC (1998).

DISCUSSION

If the objective of practical swine diet formulation is to achieve predictable biological performance and optimal financial results, then a clear understanding of the relationships between dietary energy concentration and animal growth and body composition is essential. However, despite a large number of experiments reported in the literature, such relationships are not well understood. Studies using a corn and soybean meal basal diet have often evaluated the impact of altering

Table 5. Least squares means describing the performance of pigs consuming diets containing 3.12, 3.30, or 3.43 Mcal of DE/kg of diet (Exp. 2)[1]

	Measured DE, Mcal/kg					Sex		
Item	3.12	3.30	3.43	SEM	*P*-value[2]	Barrow	Gilt	*P*-value[2]
Initial BW, kg	37.4	36.6	36.5	0.87	—	—	—	—
Final BW, kg	118.6	118.0	119.0	0.29	—	—	—	—
ADG, kg								
Day 0 to 21[3]	0.91	0.96	1.00	0.06	0.02	0.97	0.94	0.12
Day 22 to 42	0.96	1.01	1.07	0.05	0.02	1.02	1.00	0.54
Day 43 to 57	1.08	1.08	1.05	0.03	0.41	1.07	1.07	0.94
Day 57 to market[4]	0.98	0.91	0.94	0.02	0.08	0.97	0.92	0.05
Day 0 to market	0.99	0.98	1.00	0.02	0.31	1.01	0.98	0.03
ADFI, kg								
Day 0 to 21	2.09	2.11	2.08	0.07	0.74	2.13	2.05	0.03
Day 22 to 42	2.75	2.72	2.67	0.08	0.21	2.77	2.66	0.004
Day 43 to 57	3.48	3.33	3.21	0.09	0.10	3.57	3.11	<0.001
Day 57 to market	3.53	3.34	3.20	0.08	0.02	3.56	3.15	<0.001
Day 0 to market	2.94	2.85	2.77	0.04	0.01	2.97	2.74	<0.001
G:F, kg/kg								
Day 0 to 21	0.44	0.46	0.48	0.01	<0.001	0.46	0.46	0.94
Day 22 to 42	0.36	0.37	0.40	0.01	0.003	0.38	0.38	0.84
Day 43 to 57	0.32	0.33	0.33	0.02	0.34	0.30	0.35	<0.001
Day 57 to market	0.28	0.27	0.29	0.01	0.17	0.27	0.29	0.04
Day 0 to market	0.34	0.34	0.36	0.021	0.002	0.34	0.36	0.001
Energy intake, Mcal of DE/d								
Day 0 to 21	6.49	6.89	7.19	0.22	0.001	6.97	6.74	0.04
Day 22 to 42	8.51	8.92	9.27	0.31	0.001	9.06	8.74	0.004
Day 43 to 57	10.51	10.95	10.98	0.33	0.53	11.45	10.18	0.001
Day 57 to market	11.24	11.16	10.97	0.26	0.72	11.85	10.39	<0.001
Day 0 to market	9.14	9.34	9.58	0.06	0.14	9.73	8.98	<0.001
Gain, kg/Mcal of DE								
Day 0 to 21	0.14	0.14	0.14	0.004	0.60	0.14	0.14	0.88
Day 22 to 42	0.11	0.11	0.12	0.003	0.82	0.11	0.11	0.44
Day 43 to 57	0.11	0.10	0.10	0.008	0.01	0.09	0.11	<0.001
Day 57 to market	0.09	0.08	0.09	0.003	0.19	0.08	0.09	0.02
Day 0 to market	0.11	0.10	0.10	0.002	0.11	0.10	0.11	0.003
BW CV,[5] %								
Day 0	9.4	11.0	11.4	0.6	0.02	12.0	9.0	<0.001
Day 57	8.9	10.2	10.6	0.7	0.17	9.0	10.3	0.26
Tail-end pigs[6]	48	45	37	—	—	—	—	—
No. marketed[6]	183	186	187	—	—	—	—	—
Days to market[6]	79.9	80.7	79.0	—	—	—	—	—

[1] Animals (n = 720) were put on the experiment at an average BW of 36.8 ± 5.8 kg.

[2] Initial BW was used as a covariate. The model contained the effects of DE, sex, and the interaction of DE × sex.

[3] Males were on phase 1 for 4 wk, phase 2 for 4 wk, and phase 3 for the remainder of the experiment. Females were on phase 1 for 6 wk, phase 2 for 4 wk, and phase 3 for the remainder of the experiment.

[4] Marketed at approximately 118 kg.

[5] Determined on a pen basis (n = 20 pigs/pen). Average CV per room (n = 240/room): 16.1, 15.2, and 17.7 for the low, medium, and high treatments, respectively, on d 0, and 12.4, 11.8, and 12.3 for the low, medium, and high treatments, respectively, on d 57.

[6] Pigs failing to achieve the minimum market BW target at room close out. Not analyzed statistically.

Table 6. Least squares means describing carcass variables and the economic value of pigs consuming diets containing 3.12, 3.30, or 3.43 Mcal of DE/kg of diet (Exp. 2)

	Measured DE, Mcal/kg					Sex		
Item	3.12	3.30	3.43	SEM	*P*-value[1]	Barrow	Gilt	*P*-value[1]
Market BW, kg	118.8	117.8	118.9	0.60	0.02	118.6	118.4	0.54
Dressing %	78.5	79.3	79.0	0.20	0.07	78.6	79.3	0.003
Carcass index[2]	112.2	113.0	112.4	0.46	0.81	112.5	112.6	0.88
Lean yield, %	62.0	61.8	62.0	0.20	0.55	61.2	62.7	0.001
Backfat depth, mm	15.8	16.2	16.0	0.40	0.53	17.3	14.7	0.001
LM depth, mm	61.8	62.5	63.5	0.71	0.08	61.2	62.7	<0.001
Value,[3] Cdn $/pig	148.33	149.57	149.59	0.80	0.19	148.44	149.88	0.04

[1] The statistical model included the effects of treatment DE, sex, initial BW block, and all interactions. Market BW (with the exception of market BW) was used as a covariate. No interactions were significant, $P > 0.10$.

[2] Carcass index represents the basis for establishing carcass value according to the Canadian Hog Carcass Grading Settlement System (Canadian Pork Council, 1986). For example, a pig with a carcass index of 113 will receive 1.13 times the settlement price of the packer, plus any applicable premiums.

[3] Index/100 × settlement weight + premiums. Prices [2005; Canadian dollars (Cdn $)] of $1.40/kg were used.

fat concentrations; in those instances, results have been fairly consistent (Pettigrew and Moser, 1991). Those data serve a very useful purpose in regions where diets are based on corn and soybean meal and where fat sources are competitively priced; this no doubt explains the large number of experiments undertaken on this topic. However, such studies provide little insight into how pigs respond when dietary energy concentration is altered in other ways, such as through the manipulation of high- vs. low-energy basal ingredients. In such regions, fat tends to be a more expensive ingredient and is used more cautiously (Beaulieu et al., 2006).

Our understanding of the relationship between dietary energy supply and biological outcomes has tended to be based more on studies in which feed intake, and thus energy intake, was regulated as an experimental input (Campbell and Taverner, 1988; Bikker, 1994) than on studies in which diets differing in energy concentration were offered on an ad libitum basis (Ellis and Augspurger, 2001). When energy (feed) intake is controlled, increasing the energy intake results in predictable, and generally consistent, outcomes (Bikker, 1994; de Lange, 1995). However, in commercial practice in North America, feed intake is not controlled, but rather is affected by a wide variety of factors external and internal to the pig; these have been discussed in a recent review (Nyachoti et al., 2004). Although physical gut capacity is one of those factors (Black, 1995), many others affect feed intake under commercial conditions and thus have an effect on energy supply to the pig. The 2 experiments reported herein are a case in point. Daily feed intake was considerably greater in the pigs housed on the commercial farm than in the pigs housed at the Prairie Swine Centre; for example, on the lowest-energy diet, the pigs in Exp. 2 consumed 2.94 kg/d compared with 2.66 kg/d in Exp. 1. It is impossible to identify which factors explain this difference, but given that the physical conditions in the barns, the genotype used, the diet formulations used, and the health status of the herds all fell well within the normal range observed in commercial practice, the challenge of understanding or predicting feed intake, and thus the response to energy,

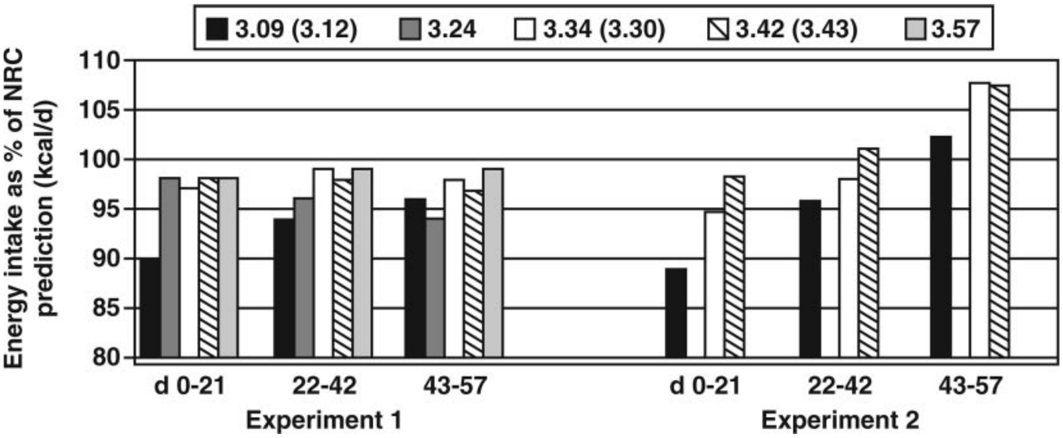

Figure 1. Energy intake (DE), expressed as a percentage of NRC (1998) predicted energy intake. Values in the legend refer to measured energy values (Mcal/kg) averaged across sexes (Exp. 2 values in parentheses).

is clear (Black, 1995). The implication for commercial practice is also clear; predicting how pigs will respond to dietary energy concentration will be very difficult unless feed intake, and especially the capacity of the pigs to adjust feed intake, is known.

In the present experiments, the pigs in Exp. 2 ate more feed and thus consumed more energy, even at the lowest dietary energy concentration, than the pigs in Exp. 1; these pigs did not respond to increases in DE content in the final growth phase. Conversely, in Exp. 1, pigs ate less feed, and thus consumed less energy, but did respond, albeit modestly, to increases in dietary energy throughout the total experiment, including the final phase. On the basis of these results, it might be speculated that the response to dietary energy concentration will depend, among other things, on the range in feed intake that is possible within a given herd. Alternatively, if pigs have the capacity to increase feed intake, and thus energy intake, as dietary DE declines, their performance is less likely to be impaired by low-energy diets. Conversely, if pigs do not have the capacity to increase feed intake as dietary DE declines, their performance is more likely to be impaired by low-energy diets. Certainly, there are many other explanations for the different responses between Exp. 1 and 2, but we advance this explanation as a working hypothesis for future research and for explaining the large differences in the response to dietary energy concentration reported in the literature. It may also help to explain the different responses to dietary energy concentrations observed in commercial practice.

It has long been suggested that smaller pigs are less likely to be able to maintain growth performance when dietary DE is reduced; this was observed in the second experiment, but not the first. De la Llata et al. (2001b) added 6% tallow to the diets of growing pigs and observed an overall improvement in ADG; however, only in phase 1 (36 to 59 kg) was the effect statistically significant. Similarly, the addition of high-fat oats to the diets of 27- to 80-kg pigs improved ADG during the growing period, but not the finishing period (Thacker et al., 2004). In Exp. 2, which was conducted at a commercial swine facility, the response to energy plateaued at approximately 80 kg. Although it is consistent with the literature to suggest that physical gut capacity may have been the limiting factor, it could also have been driven by the innate growth curve of the pig and the consequent need or demand for nutrients.

The differing responses of the animals between Exp. 1 and Exp. 2 are illustrated very well where daily energy intake is expressed as a percentage of that predicted by NRC (1998). This equation serves as a useful guide to feed intake, against a widely accepted standard; it thus serves to characterize a herd as having a high or low feed intake potential. In Exp. 1, the pigs consumed equal quantities of energy per day on all but the lowest-energy diet in phase 1. In phase 2, daily energy intake in relation to that predicted by NRC increased from the lowest-energy to the medium-energy concentration and was equal across the higher-energy diets. In phase 3, there was a general increase from the lowest-energy to the highest-energy diet. In contrast, in Exp. 2, intake relative to that predicted by NRC increased as dietary DE increased in all phases except the third, where the response was more curvilinear. These data merely confirm that daily energy intake is a function of more than pig BW (Nyachoti et al., 2004). It should be emphasized that the DE intakes reported herein are based on actual, measured DE and not on formulated DE values, eliminating formulation error as an explanation for these results.

The improvement in feed efficiency, which was seen throughout Exp. 1 and in all but the final phase of Exp. 2, is a common observation when diets with increased DE concentration are fed (Myer et al., 1992; Brumm and Miller, 1996; De la Llata 2001a,b; Thacker et al., 2004). It is typically associated with decreased feed intake rather than improved BW gain (Brumm and Miller, 1996; Smith et al., 1999).

It is very important in studies investigating dietary energy to measure actual DE because there can be large deviations between the formulated and actual DE content of the final diet. This occurs, in large part, as a result of the variation in ingredient composition (Fairbairn et al., 1999; Patience and Beaulieu, 2005). Weanling swine have a limited ability to digest lipid; however, their full digestive and absorptive capacity for fats has been reported to be achieved by 40 kg of BW (Baidoo et al., 1996). A difference in DE between corn oil and tallow was observed immediately postweaning but had narrowed by 4 wk postweaning (Cera et al., 1989). A comparison of the measured vs. formulated DE values in Exp. 1 and 2 indicated that the added fat was well utilized, even in phase 1. Nonetheless, there were important differences between formulated and actual DE values, ranging from 6 to 50 kcal of DE/kg.

Pork producers strive for maximizing lean growth and often are discouraged from adding fat to diets for finishing swine because of concerns regarding carcass quality. The effect of dietary fat on backfat thickness is variable (Myer et al., 1992; De la Llata et al., 2001b). In fact, up to 6% fat added to the diets of growing pigs (36 to 120 kg) had no effect on carcass traits in 1 experiment, whereas adding the same amount from 25 to 115 kg of BW in a second experiment resulted in increased backfat and decreased carcass leanness (De la Llata et al., 2001b). Similarly, in our experiments, backfat thickness increased and LM thickness decreased with increasing DE concentration in Exp. 1. Conversely, in the second experiment, despite a slightly heavier market BW, increasing energy tended to increase LM thickness and had no effect on backfat thickness. Most critically, however, increasing dietary energy increased dressing percentage in a linear fashion in Exp. 1 and in a curvilinear fashion in Exp. 2. This has important economic implications and needs to be considered in any model designed to relate the cost of dietary energy to changes in revenue.

An economic analysis of returns above feed costs, using either current or 5-yr average feed and animal prices, indicated no advantage to increased dietary energy in either experiment (data not shown). The analysis of Exp. 2 was repeated to consider improved space utilization within the barn because of decreased days to market when dietary energy was increased and the reduction in "tail-end" pigs (those failing to achieve the minimum market BW target at room close out). Again, the return above feed costs favored the low-energy diets. Conversely, De la Llata et al. (2001a), in a detailed economic analysis of the impact of adding 6% choice white grease to the diets of growing pigs, observed a numerical improvement in the income above feed costs with the added fat. They determined that because of the large variability in the cost of dietary fat, the opportunity margin may be greater for fat than for other ingredients. In another experiment (De la Llata et al. 2001b), they showed positive carryover effects from 95 to 115 kg of BW after removing added fat from the diet. This could have important consequences for a situation similar to Exp. 2, in which the response to added fat was observed up to approximately 80 kg. Although these economic analyses considered carcass traits measured at the abattoir and not eating quality, Wiseman et al. (2000) showed that only in extreme situations did added dietary fat affect the sensory properties of pork. In that particular study, they added 13% linseed oil. Therefore, the decision to supplement with fat should primarily be affected by economics. The likely difference in the economic conclusions of De la Llata et al. (2001a) and our own results could be related either to the relative cost of fat in the United States compared with western Canada, or to differential impacts of carcass settlement arrangements. Nonetheless, economic analysis tends to require an approach that recognizes the specific situation of individual farms, as well as the changing economic relationships of costs vs. revenue over time.

Finally, the impact of dietary energy concentration on the variability of BW, particularly at the time of marketing, was of interest. Any technique that would increase the uniformity of pigs would have the potential to improve economic returns; variation in BW reduces the efficiency with which pigs can use space and thus imposes a significant economic cost on pork producers. The data reported herein showed no benefit from increasing, or decreasing, dietary DE on the CV for BW. However, in Exp. 2, the highest-energy diet decreased the number of tail-end pigs somewhat, although the economic impact in this instance was insufficient to justify the greater diet cost.

In conclusion, the impact of increasing the energy density of the diet for growing pigs, through incremental changes in diet composition, had a variable impact on overall growth performance and carcass quality. When feed intake was less, improvements in rate of BW gain in response to increasing dietary DE appeared to be greater and more continuous throughout the whole grow-out period, as compared with circumstances in which feed intake was greater. Improvements in feed efficiency were observed consistently in both experiments; thus, changes in feed intake dictated whether growth rate was affected. Increasing dietary DE had differential effects on carcass merit in the 2 experiments, but in both, improvements in dressing percentage were observed. Increasing dietary DE had no effect on variation in BW at the time of marketing.

Selection of the economically optimal dietary energy concentration remains a challenge. However, there is reason to believe that the feed intake of a given herd, which varies greatly among herds, will help to predict the response of the herd to changes in dietary DE. This underscores the fundamental importance of knowing actual feed intake curves as a basic component of nutritional management of commercial pig herds. In addition, the observed improvement in dressing percentage in response to increased dietary DE needs to be considered in any economic analysis undertaken to determine optimal dietary DE concentrations.

LITERATURE CITED

AOAC. 1990. Official Methods of Analysis. 15th ed. Assoc. Off. Anal. Chem., Arlington, VA.

AOCS. 1998. Official Methods and Recommended Practices of the AOCS. Am. Oil Chem. Soc., Champaign, IL.

ASTM. 2003. Annual Book of ASTM Standards. American Society for Testing and Materials Standards International, West Conschohocken, PA.

Baidoo, S. K., E. J. Clowes, and F. X. Aherne. 1996. The digestible energy value of canola oil for growing pigs as measured by level of inclusion. Anim. Feed Sci. Technol. 62:111–119.

Beaulieu, A. D., C. L. Levesque, and J. F. Patience. 2006. The effects of dietary energy concentration and site of weaning on weanling pig performance. J. Anim. Sci. 84:1159–1168.

Bikker, P. 1994. Protein and lipid accretion in body components of growing pigs. PhD Diss. Wageningen Agric. Univ., Wageningen, the Netherlands.

Bikker, P., and M. W. A. Verstegen. 1994. Tissue deposition and energy metabolism in growing pigs: Effects of energy intake and nutritional history. Pages 225–228 in 13th Symp. Energy Metabolism of Farm Animals, Granada, Spain. Proc. EAAP Publ. 76. Eur. Assoc. Anim. Prod., Madrid, Spain.

Black, J. L. 1995. Modelling energy metabolism in the pig—Critical evaluation of a simple reference model. Pages 87–102 in Modelling Growth in the Pig. P. J. Moughan, M. W. A. Verstegen, and M. I. Visser-Reyneveld, ed. Wageningen Press, Wageningen, the Netherlands.

Brumm, M. C., and P. S. Miller. 1996. Response of pigs to space allocation and diets varying in nutrient density. J. Anim. Sci. 74:2730–2737.

Campbell, R. G., and A. C. Dunkin. 1990. Feeding growers and finishers. Pages 85–99 in Pig Production in Australia. J. A. A. Gardner, A. C. Dunkin, and L. C. Lloyd, ed. Butterworths Pty. Ltd., Sydney, Australia.

Campbell, R. G., and M. R. Taverner. 1988. Genotype and sex effects on the relationship between energy intake and protein deposition in growing pigs. J. Anim. Sci. 66:676–686.

Canadian Council on Animal Care. 1993. Guide to the Care and Use of Experimental Animals. Vol. 1. 2nd ed. E. D. Olfert, B. M. Cross, and A. A. McWilliam, ed. Can. Counc. Anim. Care, Ottawa, Ontario, Canada.

Canadian Pork Council. 1986. The Canadian Hog Carcass Grading/Settlement System. Can. Pork Counc., Ottawa, Ontario, Canada.

Cera, K. R., D. C. Mahan, and G. A. Reinhart. 1989. Apparent fat digestibilities and performance responses of postweaning swine fed diets supplemented with coconut oil, corn oil or tallow. J. Anim. Sci. 67:2040–2047.

De la Llata, M., S. S. Dritz, M. R. Langemeier, M. D. Tokach, R. D. Goodband, and J. L. Nelssen. 2001a. Economics of increasing lysine-calorie ratio and adding dietary fat for growing-finishing pigs reared in a commercial environment. J. Swine Health Prod. 9:215–223.

De la Llata, M., S. S. Dritz, M. D. Tokach, R. D. Goodband, J. L. Nelssen, and T. M. Loughin. 2001b. Effects of dietary fat on growth performance and carcass characteristics of growing-finishing pigs reared in a commercial environment. J. Anim. Sci. 79:2643–2650.

de Lange, C. F. M. 1995. Framework for a simplified model to demonstrate principles of nutrient partitioning for growth in the pig. Pages 71–85 in Modelling Growth in the Pig. P. J. Moughan, M. W. A. Verstegen, and M. I. Visser-Reyneveld, ed. Wageningen Press, Wageningen, the Netherlands.

Ellis, M., and N. Augspurger. 2001. Feed intake in growing-finishing pigs. Pages 447–467 in Swine Nutrition. A. J. Lewis and L. L. Southern ed. CRC Press, Boca Raton, FL.

Ewan, R. C. 1986. Voluntary feed intake of swine. Pages 93–99 in Proc. Cornell Nutr. Conf. Feed Manuf., Ithaca, NY.

Fairbairn, S. L., J. F. Patience, H. L. Classen, and R. T. Zijlstra. 1999. The energy content of barley fed to growing pigs: Characterizing the nature of its variability and developing prediction equations for its estimation. J. Anim. Sci. 77:1502–1512.

King, R. H. 1999. Nutritional constraints to pig performance and variability. Pages 245–251 in Manipulating Pig Production VII. P. D. Cranwell, ed. Australas. Pig Sci. Assoc., Victoria, Australia.

McCarthy, J. F., F. X. Aherne, and D. B. Okai. 1974. Use of HCl insoluble ash as an index material for determining apparent digestibility with pigs. Can. J. Anim. Sci. 54:107–109.

Myer, R. O., J. W. Lamkey, W. R. Walker, J. H. Brendemuhl, and G. E. Combs. 1992. Performance and carcass characteristics of swine when fed diets containing canola oil and added copper to alter the unsaturated:saturated ratio of pork fat. J. Anim. Sci. 70:1417–1423.

NRC. 1998. Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, DC.

Nyachoti, C. M., R. T. Zijlstra, C. F. M. de Lange, and J. F. Patience. 2004. Voluntary feed intake in growing-finishing pigs: A review of the main determining factors and potential approaches for accurate predictions. Can. J. Anim. Sci. 84:549–566.

Patience, J. F., and A. D. Beaulieu. 2005. The merits, benefits, and challenges of adopting the net energy system in a North American context. Pages 134–150 in Proc. Minn. Nutr. Conf., Minneapolis, MN.

Pettigrew, J. E., and R. L. Moser. 1991. Fat in swine nutrition. Pages 133–145 in Swine Nutrition. E. R. Miller, D. E. Ullrey, and A. J. Lewis, ed. Butterworth-Heinemann, Boston, MA.

Smith, J. W. II, M. D. Tokach, P. R. O'Quinn, J. L. Nelssen, and R. D. Goodband. 1999. Effects of dietary energy density and lysine:calorie ratio on growth performance and carcass characteristics of growing-finishing pigs. J. Anim. Sci. 77:3007–3015.

Thacker, P. A., H. W. Soita, and B. G. Rossnagel. 2004. Performance of growing-finishing pigs fed barley-based diets supplemented with normal or high-fat oats. Can. J. Anim. Sci. 84:229–236.

Wiseman, J., M. S. Redshaw, S. Jagger, G. R. Nute, and J. D. Wood. 2000. Influence of type and dietary rate of inclusion of oil on meat quality of finishing pigs. Anim. Sci. 70:307–315.