Effects of dietary fat on growth performance and carcass characteristics of growing-finishing pigs reared in a commercial environment

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ABSTRACT: We conducted two experiments to evaluate the effects of added choice white grease on performance and carcass merit of barrows and gilts reared under commercial conditions. Pigs were housed either 20 (Exp. 1) or 25 (Exp. 2) per pen and were provided 0.67 m^2 of pen space per pig. Diets were based on corn and soybean meal and fed in a meal form. The proportion of soybean meal was increased in diets with added fat to maintain the same calorie:lysine ratio in all diets within a weight phase. In Exp. 1, 480 pigs were fed diets with 0, 2, 4, or 6% fat. Total lysine contents of the control diets were 1.21, 0.88, and 0.66% during the weight phases 36 to 59, 59 to 93, and 93 to 120 kg, respectively. Gain:feed was increased linearly ($P < 0.01$) due to fat addition in all weight intervals and over the total experiment. The effect of added fat on ADG was not consistent among the weight phases; a linear ($P < 0.01$) improvement was found from 36 to 59 kg, but no effect was found during the heavier weight phases. Over the total experiment, however, ADG was improved ($P < 0.01$) linearly. Carcass traits were not affected by treatment. Experiment 2 used 900 pigs to evaluate possible carryover effects on performance and carcass merit from feeding 6% fat. The experiment was divided into four phases: 25 to 45, 45 to 70, 70 to 90, and 90 to 115 kg; lysine contents of the control diets fed in each phase were 1.23, 1.05, 0.81, and 0.63%, respectively. The six treatments consisted of no added fat throughout the experiment or 6% added fat fed from 25 to 45 kg, 25 to 70 kg, 25 to 90 kg, 25 to 115 kg, or 45 to 70 and 90 to 115 kg. Carryover effects for ADG and G:F ($P < 0.07$) were found for the 90- to 115-kg interval and for ADFI and ME intake ($P < 0.05$) for the 45- to 70- and 70- to 90-kg intervals. When fat was added in the previous weight interval, ADG and G:F were improved and ADFI and ME intake were decreased in the subsequent weight interval. Pigs fed fat from 25 to 115 kg had more ($P < 0.05$) backfat and lower ($P < 0.05$) carcass leanness than pigs on the other treatments. These data suggest that fat can be added or removed from diets of growing-finishing pigs without any detrimental carryover effects. In fact, the positive carryover effect on ADG and G:F from 95 to 115 kg suggests that feeding fat from 25 to 95 kg will maximize performance over the total growing-finishing period but minimize any detrimental effects of added fat on carcass leanness.

Key Words: Dietary Fat, Energy, Pigs

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Introduction

Adding fat to diets for growing-finishing pigs typically improves ADG and gain:feed ratio (**G:F**), reduces ADFI, and increases carcass fatness (Pettigrew and Moser, 1991). Most of the studies evaluating dietary fat were performed in university research facilities with low animal density and good environments, which result in higher growth rates and feed intakes than those that occur in commercial swine production (Koketsu, 1997).

In the commercial industry, it is common for fat to be added or removed from growing-finishing pigs' diets at different stages of growth based on ingredient prices, the expected biological effect, and feed processing systems. The potential carryover effect due to removal of dietary fat at different stages of growth has not been evaluated under commercial conditions.

The first objective of this research was to determine the level of added dietary fat that optimized performance and carcass merit of pigs housed under commercial con-

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ditions. The second objective was to determine possible carryover effects caused by removal of fat from the diet of growing-finishing pigs reared in a commercial environment.

Materials and Methods

Experiment 1. A total of 240 barrows and 240 gilts (PIC L 366 × C14) with an initial weight of 36 kg were used to evaluate the effects of increasing added dietary fat on growth performance and carcass characteristics of growing-finishing pigs raised under commercial conditions. Pigs were selected randomly from a 6,000-pig nursery group that had been weaned within a 5-d period and allotted in a completely randomized design with 20 pigs per pen. There were 12 pens of barrows and 12 pens of gilts. Pigs were allowed ad libitum access to feed and water during the experiment.

Housing. Pigs were housed in a commercial research barn containing 24 pens with totally slatted floors. Pens were equipped with a cup waterer and four-hole feeder and measured 2.44 × 5.49 m, which provided 0.67 m^2 per pig. The research facility is located on a site with four 1,000-pig finishing barns and is managed all-in, all-out, by site. The experiment was conducted from June to September 1997.

Treatments. The treatments were arranged in a 2 × 4 factorial in a completely randomized design. Main effects were sex and corn-soybean meal-based diets with 0, 2, 4, or 6% choice white grease. Vitamins, trace minerals, and all other nutrients met or exceeded the requirements suggested by NRC (1998). Diets were fed in three phases with lysine:calorie ratios of 3.67, 2.67, and 1.97 g total lysine/Mcal ME for phases 1 (36 to 59 kg), 2 (59 to 93 kg), and 3 (93 to 120 kg), respectively (Table 1). Diets were switched on the day when the average weight for all pens of a given sex reached 59 and 93 kg.

Growth Performance and Carcass Composition. Pigs were weighed on a weekly basis to determine ADG. Feed delivery was recorded daily, and feed remaining in the feeders was weighed weekly to determine feed intake and feed efficiency. At the end of the last phase, pigs were weighed before transport to a USDA-inspected processing plant, where carcass data were collected (Swift and Co., Worthington, MN). Prior to transport, the pigs in each pen were marked with a distinctive tattoo to allow the carcass data to be recorded for each pen. Yield was calculated as hot carcass weight divided by body weight. Fat depth and loin depth were measured with an optical probe inserted between the third and fourth from the last rib, 7 cm off of the midline of the hot carcass. Lean percentage was provided from the packing plant using a proprietary equation and fat-free lean index was calculated according to NPPC (1994) procedures.

Statistical Analysis. Data were analyzed as a completely randomized design using GLM procedures (SAS Inst. Inc., Cary, NC) with linear and quadratic polynomial contrasts (Peterson, 1985) to determine the effect of increasing amounts of added fat in the diets. Carcass data were analyzed with hot carcass weight as a covariate. The statistical model included the main and interactive effects of sex and added fat. Pen was the experimental unit for all analyses.

Experiment 2. A total of 450 barrows and 450 gilts (PIC 337 × C22) with an initial weight of 25 kg were used to determine the possible carryover effects of adding and removing dietary fat on growth performance and carcass characteristics. Pigs in this experiment were selected from a 1,200-pig nursery group. The nursery group was 1 wk of production from a 3,000-sow farm.

Housing. Pigs were housed in a commercial research barn in southwestern Minnesota with 25 pigs per pen and six pens/treatment. Each pen was equipped with a four-hole self-feeder and one cup waterer. Pen dimensions were 3.05 × 5.49 m, which provided 0.67 m^2 per pig. The finishing facility was a double-curtain-sided, deep-pit barn with totally slatted floor pens. Barrows and gilts were penned separately by weight in groups of six consecutive pens, as they were loaded into the finishing barn from the nursery. Each group of six pens was randomly assigned either barrows or gilts. The facility was one of four barns in a site that is managed all-in, all-out, by barn. The experiment was conducted from March to July 1999.

Treatments. One pen within each group of six pens of barrows or gilts was assigned randomly to one of six dietary treatments in a split-plot crossover design. The corn-soybean meal-based diets (Table 2) were fed in four 28-d phases, which resulted in average initial and final pig weights of 25 to 45, 45 to 70, 70 to 90, and 90 to 115 kg. The lysine:calorie ratios were identical within each phase and were 3.72, 3.17, 2.42, and 1.90 g total lysine/Mcal ME for phases 1, 2, 3, and 4, respectively. All other nutrients met or exceeded the requirements provided by NRC (1998). The treatments consisted of six different sequences of adding fat to the diets across the four phases (Table 3). Treatments were diets with no added fat fed from 25 to 115 kg and diets with 6% fat fed from 25 to 45, 25 to 70 kg, 25 to 90 kg, 25 to 115 kg, or from 45 to 70 and 90 to 115 kg.

Growth and Carcass Composition Data. Pig weights by pen and feed disappearance were measured every 14 d to calculate ADG, ADFI, and G:F. Diet changes occurred for all pens every 28 d. At the termination of the study, pigs were sent to the same facility as in Exp. 1 and carcass data were collected in a similar manner.

Statistical Analysis. The analysis of variance model combined standard models for split-plot and crossover designs using the MIXED procedure of SAS (SAS Inst. Inc.) to determine the direct carryover effects of adding and removing dietary fat during phases. A significant carryover effect indicates a response that is influenced by the dietary fat level fed in the previous phase. Treatment combinations used to evaluate carryover effects are listed in Table 4. Sex (whole plot) was assigned to groups of six consecutive pens, and the treatment sequences (subplots) were assigned to individual pens. Each treat-

Table 1. Percentage composition of diets used in Exp. 1[a]

Item	Weight phase		
	36 to 59 kg	59 to 93 kg	93 to 120 kg
Ingredient			
Corn	62.35–52.59	75.20–65.94	83.18–75.01
Soybean meal (46.5% CP)	35.04–38.84	22.83–26.09	14.86–17.03
Monocalcium phosphate (21% P)	1.37–1.36	0.76–0.79	0.78–0.79
Limestone	0.71–0.69	0.74–0.71	0.73–0.72
Salt	0.35	0.35	0.35
Vitamin premix[b]	0.05	0.045	0.040
Trace mineral premix[c]	0.10	0.075	0.065
Choice white grease	0–6	0–6	0–6
Calculated analysis[d]			
CP, %	21.71–22.61	17.15–17.86	14.14–14.45
Lysine, %	1.21–1.30	0.875–0.95	0.655–0.70
ME, Mcal/kg	3.31–3.58	3.34–3.61	3.35–3–61
Lysine:calorie ratio, g lysine/Mcal ME	3.67	2.67	1.97
Ca, %	0.70	0.55	0.53
Available P, %	0.34	0.22	0.21

[a]As-fed basis. Diets contained either 0, 2, 4, or 6% choice white grease.
[b]Provided the following per kilogram of premix: vitamin A, 7,700,000 IU; vitamin D, 1,100,00 IU; vitamin E, 4,400 IU; menadione (menadione sodium bisulfate complex), 2,200 mg; vitamin B_{12}, 39.6 mg; riboflavin, 9,900 mg; pantothenic acid, 33,000 mg; and niacin, 43,780 mg.
[c]Provided the following per kilogram of premix: Mn, 20 g; Fe, 120 g; Zn, 120 g; Cu, 15 g; I, 400 mg; Se, 200 mg.
[d]Calculated analyses were based on nutrient contents of ingredients listed in NRC (1998).

ment sequence represented two levels of added dietary fat in a four-period crossover experiment. The model included fixed effects for sex, fat, phase, carryover, sex × fat, sex × carryover, phase × fat, sex × phase × fat, phase × carryover, and sex × phase × carryover. *F*-tests were computed for each fixed effect, and contrasts were tested comparing the two fat levels for different sexes, phases, and sex × phase interactions.

The overall growth performance and carcass composition data were analyzed using ANOVA with least squares mean comparisons to determine differences between the six dietary treatments. The statistical model included fixed effects for sex (whole plot), sequence arrangement (subplots), and sex × sequence arrangement. Pen was the experimental unit. Hot carcass weight was used as a covariate in the analyses of carcass data.

Table 2. Percentage composition of diets used in Exp. 2[a]

Item	Phase							
	25 to 45 kg		45 to 70 kg		70 to 90 kg		90 to 115 kg	
Ingredient, %								
Corn	64.86	51.99	68.48	59.05	77.68	69.04	83.87	75.95
Soybean meal (46.5% CP)	35.24	39.13	28.70	32.18	19.62	22.26	13.51	15.43
Monocalcium phosphate (21% P)	1.30	1.28	1.25	1.20	1.20	1.20	1.13	1.13
Limestone	1.03	1.03	1.00	1.00	0.99	0.99	0.98	0.98
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[b]	0.075	0.075	0.075	0.075	0.063	0.063	0.063	0.063
Trace mineral premix[c]	0.15	0.15	0.15	0.15	0.10	0.10	0.10	0.10
Choice white grease	—	6	—	6	—	6	—	6
Calculated analysis[d]								
CP, %	21.60	22.60	19.20	20.0	15.70	16.20	13.40	13.6
Lysine, %	1.23	1.33	1.05	1.14	0.81	0.87	0.63	0.68
ME, Mcal/kg	3.31	3.58	3.32	3.59	3.33	3.60	3.34	3.61
Lysine:calorie ratio, g lysine/Mcal ME	3.72	3.72	3.17	3.17	2.42	2.42	1.90	1.90
Ca, %	0.77	0.77	0.73	0.73	0.69	0.69	0.65	0.65
Available P, %	0.35	0.35	0.33	0.33	0.31	0.31	0.29	0.29

[a]As-fed basis. Diets in each phase contained either 0 or 6% choice white grease.
[b]Provided the following per kilogram of premix: vitamin A, 8,800,000 IU; vitamin D, 1,300,000 IU; vitamin E, 35,000 IU; menadione (menadione sodium bisulfate complex), 2,900 mg; vitamin B_{12}, 35.2 mg; riboflavin, 5,400 mg; pantothenic acid, 26,400 mg; and niacin, 32,400 mg.
[c]Provided the following per kilogram of premix: Mn, 26 g; Fe, 110 g; Zn, 110 g; Cu, 11 g; I, 198 mg; Se, 198 mg.
[d]Calculated analyses were based on nutrient contents of ingredients listed in NRC (1998).

Table 3. Arrangement of treatments for Exp. 2

	Dietary fat addition, % (sequence)					
Phase	1	2	3	4	5	6
1 (25 to 45 kg)	0	**6**	**6**	**6**	**6**	0
2 (45 to 70 kg)	0	0	**6**	**6**	**6**	**6**
3 (70 to 90 kg)	0	0	0	**6**	**6**	0
4 (90 to 115 kg)	0	0	0	0	**6**	**6**

Results

Experiment 1. Because no sex × treatment interactions occurred ($P > 0.22$), data for barrows and gilts were pooled. During phase 1 (36 to 59 kg), increasing added dietary fat increased (linear, $P < 0.01$) ADG and G:F and tended (linear, $P < 0.07$) to increase gain:ME ratio (**G:ME**) (Table 5). Average daily feed intake and energy intake were not affected by fat addition. During phase 2 (59 to 93 kg) added fat increased G:F (linear, $P < 0.01$) but had no effect on ADFI or energy intake. During phase 3 (93 to 120 kg), ADG was not affected by added dietary fat, but ADFI decreased (linear, $P < 0.03$), G:F increased (linear, $P < 0.01$), and G:ME tended to increase (linear, $P < 0.09$) as added dietary fat was increased. Energy intake was not affected. For the overall period, ADG, G:F, and G:ME increased (linear, $P < 0.04$), but energy intake was not affected as dietary fat increased. Dietary treatment did not affect carcass yield, backfat or loin depth, or lean percentage.

Experiment 2. Data for barrows and gilts were pooled because no significant ($P > 0.19$) interactions of sex and treatments occurred during any of the four phases or for the entire experiment. During phase 1 (25 to 45 kg), ADG was not affected by added dietary fat (Table 6). During phases 2 (45 to 70 kg) and 3 (70 to 90 kg), ADG was increased ($P < 0.05$) when dietary fat was included in the diet. No carryover effects were found. In phase 4 (90 to 115 kg), ADG was not affected by added dietary fat, but a carryover effect ($P < 0.06$) was detected. Pigs fed diets containing 6% added fat in the previous phase grew faster than pigs fed a diet containing no added fat during the previous phase. For the overall period (Table 10), ADG was not affected when fat was added to the diet.

Table 4. Treatment combinations used to evaluate carryover effects in Exp. 2

Phase	Added fat in previous phase, %	Added fat in current phase, %	
		0	6
25 to 45 kg		1, 6	2, 3, 4, 5
45 to 70 kg	0	1	6
	6	2	3, 4, 5
70 to 90 kg	0	1, 2	
	6	3, 6	4, 5
90 to 115 kg	0	1, 2, 3	6
	6	4	5

Average daily feed intake was decreased ($P < 0.05$) during phase 1 (25 to 45 kg) when fat was included in the diet (Table 7). During phase 2 (45 to 75 kg), ADFI was not affected by added dietary fat, but a carryover effect ($P < 0.05$) was observed. Pigs fed 6% added dietary fat in phase 1 had lower feed intake during phase 2 than pigs fed no added dietary fat during phase 1. During phase 3 (70 to 90 kg), a tendency ($P < 0.08$) for a decrease in ADFI was observed when fat was added to the diet, and a carryover effect also was detected ($P < 0.05$). Pigs fed added fat during phase 2 had lower ADFI during phase 3 than pigs fed no added dietary fat during phase 2. During phase 4 (90 to 115 kg), adding dietary fat decreased ($P < 0.05$) ADFI, and no carryover effect was observed. For the overall period, the treatment sequence with 6% added dietary fat in all phases (Table 10) resulted in the lowest ($P < 0.05$) ADFI. Pigs fed added dietary fat during the first two or three phases had intermediate ($P < 0.05$) ADFI compared with pigs fed fat only in phase 1 and pigs fed fat in all four phases.

Energy intake was not affected by adding fat from 25 to 45 kg (Table 8). During phases 2 (45 to 70 kg) and 3 (70 to 90 kg), energy intake increased when 6% added fat was included in the diet. A carryover effect ($P < 0.05$) was observed in both phases. Pigs fed added dietary fat during the previous phase had decreased energy intake compared to pigs fed no added dietary fat during the previous phase. In phase 4 (90 to 115 kg), energy intake was not affected by added dietary fat and no carryover effect was observed. For the overall period (Table 10), energy intake was not affected by adding fat to the diet.

Gain:feed ratio was increased ($P < 0.05$) during all phases (Table 9) and for the overall experiment when dietary fat was added (Table 10). No carryover effects were observed for phases 2 (45 to 70 kg) or 3 (70 to 90 kg). During phase 4 (90 to 115 kg), a tendency ($P < 0.07$) for a carryover effect was detected. Adding fat in the previous phase tended to improve G:F compared to treatments with no added fat in the previous phase.

Hot carcass yield was not affected by the dietary treatments. Backfat depth increased ($P < 0.05$) and percentage lean and fat-free lean index decreased ($P < 0.05$) for the dietary treatment containing 6% added fat in all phases. No differences in backfat depth, percentage lean, or fat-free lean index were found among pigs fed any of the other experimental treatments.

Discussion

Experiment 1. The improvement in ADG caused by increasing dietary fat during phase 1 (36 to 59 kg) agrees with the results reported by Stahly et al. (1981), Campbell and Taverner (1988), and Southern et al. (1989). The positive response implies that pigs in this study were in an energy-dependent phase of growth up to 59 kg. Bikker et al. (1996a,b) observed that gilts from 45 to 85 kg were in an energy-dependent phase, because protein deposition increased with increasing energy intake. Increasing the energy density of the diet from 93

Table 5. Effect of increasing levels of dietary fat on growth performance and carcass characteristics of growing-finishing pigs (Exp. 1)[a]

	Added dietary fat, %					Probability ($P <$)	
Item	0	2	4	6	SEM	Linear	Quadratic
Phase 1 (36 to 59 kg)							
ADG, kg	811	831	858	895	14.9	0.01	0.57
ADFI, kg	1.87	1.82	1.82	1.81	0.05	0.45	0.75
ME intake, Mcal/d	6.18	6.20	6.34	6.47	0.18	0.23	0.77
Gain:feed	0.436	0.456	0.472	0.496	0.009	0.01	0.86
Gain:ME, g/Mcal	132	134	135	139	2.6	0.07	0.85
Phase 2 (59 to 93 kg)							
ADG, g	722	717	759	758	20.8	0.13	0.93
ADFI, kg	2.19	2.12	2.14	2.06	0.07	0.28	0.98
Energy intake, Mcal/d	7.31	7.27	7.52	7.44	0.26	0.60	0.90
Gain:feed	0.330	0.339	0.358	0.369	0.006	0.01	0.90
Gain:ME, g/Mcal	99	99	101	102	1.9	0.14	0.90
Phase 3 (93 to 120 kg)							
ADG, g	697	702	737	717	18.2	0.26	0.52
ADFI, kg	2.56	2.47	2.48	2.33	0.05	0.03	0.57
Energy intake, Mcal/d	8.55	8.48	8.75	8.44	0.20	0.93	0.53
Gain:feed	0.273	0.284	0.297	0.307	0.005	0.01	0.92
Gain:ME, g/Mcal	82	83	84	85	1.5	0.09	0.95
Overall							
ADG, g	737	741	779	782	12.5	0.01	0.97
ADFI, kg	2.20	2.14	2.15	2.07	0.05	0.13	0.91
Energy intake, Mcal/d	7.35	7.32	7.56	7.47	0.18	0.52	0.88
Gain:feed	0.336	0.347	0.363	0.378	0.006	0.01	0.84
Gain:Me, g/Mcal	100	102	103	105	1.6	0.04	0.82
Final weight, kg	118.05	118.14	120.63	121.50	1.43	0.06	0.78
Carcass data							
Carcass weight, kg	86.13	88.39	90.78	91.11	1.33	0.01	0.49
Yield, %[b]	76.28	76.67	76.25	76.53	0.26	0.84	0.87
Backfat depth, mm[b]	17.24	18.52	16.63	18.52	0.39	0.33	0.42
Loin depth, mm[b]	58.18	58.88	58.05	57.65	0.57	0.40	0.32
Lean percentage[b]	55.28	54.65	55.61	54.44	0.24	0.22	0.27

[a]A total of 480 growing-finishing pigs (six pens per treatment and 20 pigs per pen) with an initial weight of 36 kg.
[b]Values adjusted for differences in carcass weight by covariate analysis.

Table 6. Effects of adding and removing dietary fat on average daily gain (g) of growing-finishing pigs reared in a commercial environment (Exp. 2)[a]

		Added fat in current phase			Probability ($P <$)	
Phase[bc]	Added fat in previous phase, %	0%	6%	SEM[d]	Fat	Carryover
25 to 45 kg		674	709	25	0.25	—
45 to 70 kg	0	721	820	26	0.05	0.88
	6	717	816			
70 to 90 kg	0	789	—[e]	29	0.05	0.27
	6	754	852			
90 to 115 kg	0	801	818	26	0.56	0.06
	6	867	884			

[a]A total of 900 growing-finishing pigs (six pens per treatment and 25 pigs per pen) with an initial weight of 25 kg.
[b]Means are based on the presence or absence of added dietary fat in the current and previous phase. Dietary treatments used to obtain each mean are listed in Table 4.
[c]Average daily gain was different ($P < 0.05$) between phases. The effect of added dietary fat on ADG was not constant across phases (phase × fat interaction, $P < 0.05$).
[d]Standard errors are pooled values for all treatments without fat or with 6% added fat within each phase.
[e]Sequence does not exist (see treatment sequence arrangement in Table 3).

Table 7. Effects of adding and removing dietary fat on average daily feed intake (kg) of growing-finishing pigs reared in a commercial environment (Exp. 2)[a]

Phase[bc]	Added fat in previous phase, %	Added fat in current phase 0%	6%	SEM[d]	Probability (P <) Fat	Carryover
25 to 45 kg		1.50	1.35	0.05	0.05	—
45 to 70 kg	0	1.87	1.83	0.05	0.26	0.05
	6	1.76	1.73			
70 to 90 kg	0	2.42	—[e]	0.05	0.08	0.05
	6	2.30	2.23			
90 to 115 kg	0	2.75	2.58	0.06	0.05	0.40
	6	2.71	2.54			

[a]A total of 900 growing-finishing pigs (six pens per treatment and 25 pigs per pen) with an initial weight of 25 kg.
[b]Means are based on the presence or absence of added dietary fat in the current and previous phase. Dietary treatments used to obtain each mean are listed in Table 4.
[c]Average daily feed intake was different ($P < 0.05$) between phases. The effect of added dietary fat on ADFI was not constant across phases (phase × fat interaction, $P < 0.05$).
[d]Standard errors are pooled values for all treatments without fat or with 6% added fat within each phase.
[e]Sequence does not exist (see treatment sequence arrangement in Table 3).

to 120 kg did not improve ADG, suggesting that pigs during this phase were not in an energy-dependent phase. Similar results were observed by Smith et al. (1999), who showed no improvement in ADG from 73 to 104 kg with added dietary fat. Moreover, they reported a quadratic decrease in ADG as dietary fat was increased in the diet. Published reports evaluating dietary fat for pigs during the late finishing period (> 95 kg) are scarce.

Several factors such as high stocking density, regrouping, group-housing, and high temperature lead to reduced ADFI (Hyun et al., 1998; Morgan et al. 1999; Gomez et al., 2000). Thus, feed intake would be expected to be lower under commercial conditions than in controlled research settings. For example, in Exp. 1 ADFI was approximately 25% less than the ADFI of pigs fed similar diets under a university research setting (Smith et al., 1999). If energy intake levels under ideal conditions (university research environment) are close to or right at the potential for maximum voluntary energy intake, an increase in the energy content of the diet would lead to a reduction in feed intake, but not in energy intake. Under many commercial conditions in which energy intake is significantly below the potential for maximum energy intake, an increase in the energy density of the diet would not decrease feed intake and probably would increase growth rate. The pig's voluntary energy intake is a function of the energy requirement for maintenance and growth (Schinckel, 1999). Thus, during phase 3, pigs probably were consuming energy levels high enough to meet their growth requirements; thus, an increase in energy density of the diet did not improve ADG as observed in phase 1. Adding dietary fat improved

Table 8. Effects of adding and removing dietary fat on average daily ME intake (Mcal) of growing-finishing pigs reared in a commercial environment (Exp. 2)[a]

Phase[bc]	Added fat in previous phase, %	Added fat in current phase 0%	6%	SEM[d]	Probability (P <) Fat	Carryover
25 to 45 kg		4.95	4.85	0.18	0.45	—
45 to 70 kg	0	6.201	6.54	0.18	0.05	0.05
	6	5.87	6.21			
70 to 90 kg	0	8.05	—[e]	0.19	0.05	0.05
	6	7.65	8.01			
90 to 115 kg	0	9.14	9.26	0.19	0.45	0.43
	6	9.03	9.15			

[a]A total of 900 growing-finishing pigs (six pens per treatment and 25 pigs per pen) with an initial weight of 25 kg.
[b]Means are based on the presence or absence of added dietary fat in the current and previous phase. Dietary treatments used to obtain each mean are listed in Table 4.
[c]Average daily energy intake was different ($P < 0.05$) between phases. The effect of added dietary fat on daily energy intake was not constant across phases (phase × fat interaction, $P < 0.05$).
[d]Standard errors are pooled values for all treatments without fat or with 6% added fat within each phase.
[e]Sequence does not exist (see treatment sequence arrangement in Table 3).

Table 9. Effects of adding and removing dietary fat on gain:feed ratio of growing-finishing pigs reared in a commercial environment (Exp. 2)[a]

Phase[bc]	Added fat in previous phase, %	Added fat in current phase 0%	6%	SEM[d]	Probability (P <) Fat	Carryover
25 to 45 kg		0.460	0.524	0.01	0.05	—
45 to 70 kg	0	0.390	0.455	0.01	0.05	0.15
	6	0.408	0.473			
70 to 90 kg	0	0.329	—[e]	0.01	0.05	0.93
	6	0.330	0.382			
90 to 115 kg	0	0.292	0.323	0.01	0.05	0.07
	6	0.317	0.348			

[a]A total of 900 growing-finishing pigs (six pens per treatment and 25 pigs per pen) with an initial weight of 25 kg.
[b]Means are based on the presence or absence of added dietary fat in the current and previous phase. Dietary treatments used to obtain each mean are listed in Table 4.
[c]Average daily energy intake was different ($P < 0.05$) between phases. The effect of added dietary fat on daily energy intake was not constant across phases (phase × fat interaction, $P < 0.05$).
[d]Standard errors are pooled values for all treatments without fat or with 6% added fat within each phase.
[e]Sequence does not exist (see treatment sequence arrangement in Table 3).

feed efficiency and efficiency of energy utilization (G:ME) in a manner similar to that as reported by others (Stahly and Cromwell, 1979; Stahly et al., 1981; Smith et al., 1999).

The linear responses obtained with graded levels of added dietary fat under commercial conditions indicate that the highest level should be fed when it is economical to do so (De La Llata et al., 2001). Therefore, based on these results, we used 6% added dietary fat in Exp. 2.

Experiment 2. The overall effects on growth performance due to added fat were similar to those observed in Exp. 1 and in previous studies (Pettigrew and Moser, 1991; Azain et al., 1991; Smith et al., 1999) in which G:F was consistently increased and ADFI decreased when fat was added to diets of growing-finishing pigs. Therefore, our discussion of this experiment will focus mainly on the carryover effects of adding and removing dietary fat during the different phases of growth. The carryover effect of adding and removing dietary fat has not been evaluated previously under commercial conditions.

No carryover effects were observed in ADG during phases 2 (45 to 70 kg) or 3 (70 to 90 kg), indicating that the observed response to diets without fat or with 6% added fat during each phase was not influenced by the presence or absence of dietary fat in the previous phase. In these phases, ADG was increased for the dietary treat-

Table 10. Effects of dietary treatments on growth performance and carcass characteristics of pigs from 25 to 115 kg (Exp. 2)[a]

Item		Added fat, %						SEM
	Phase 1:	0	6	6	6	6	0	
	Phase 2:	0	0	6	6	6	6	
	Phase 3:	0	0	0	6	6	0	
	Phase 4:	0	0	0	0	6	6	
ADG, g		754	759	753	778	782	781	20
ADFI, kg		1.97[bc]	2.01[b]	1.92[c]	1.91[c]	1.83[d]	1.99[bc]	0.04
Energy intake, Mcal/d		6.57	6.76	6.56	6.66	6.56	6.90	0.15
Gain:feed		0.378[bc]	0.375[b]	0.389[bc]	0.405[d]	0.421[e]	0.391[cd]	0.006
Final weight, kg		114.2	115.8	115.3	116.4	117.3	115.5	2.53
Carcass data								
Carcass weight, kg		89.18	89.03	88.38	91.02	92.97	92.91	
Yield, %[f]		75.96	74.87	74.20	76.57	76.48	77.64	1.39
Backfat depth, mm[f]		18.98[b]	19.20[b]	18.75[b]	19.18[b]	20.57[c]	19.51[b]	0.38
Loin depth, mm[f]		55.89[b]	56.09[bc]	55.64[b]	55.31[b]	56.74[bc]	57.90[c]	0.76
Lean percentage[f]		54.02[b]	54.05[b]	54.14[b]	53.81[b]	52.85[c]	54.05[b]	0.20
Fat-free lean index[f]		49.35[b]	49.25[b]	49.46[b]	49.25[b]	48.57[c]	49.11[b]	0.18

[a]A total of 900 growing-finishing pigs (six pens per treatment and 25 pigs per pen) with an initial weight of 25 kg.
[b,c,d,e]Means in the same row with different superscript differ ($P < 0.05$).
[f]Values adjusted for differences in carcass weight by covariate analysis.

ments containing 6% added fat. A carryover effect was detected from 90 to 120 kg (phase 4), suggesting that regardless of whether added dietary fat was fed during this phase, ADG increased for pigs previously fed diets containing 6% added fat. No differences in ADG were observed when comparing treatments without fat or with 6% added fat during this phase. This does not agree with data from Smith et al. (1999), who observed that ADFI and ADG were decreased from 73 to 91 kg when pigs were previously fed either 3 or 6% added dietary fat from 30 to 73 kg. We believe the difference in university (near ideal) and commercial conditions may be responsible for the discrepancy.

A carryover effect was observed during phases 2 (45 to 70 kg) and 3 (70 to 90 kg) for ADFI. Treatments without fat or with 6% added fat during phase 2 and without added fat during phase 3 had decreased ADFI when a 6% added-fat diet was fed in the previous phase. This response is similar to the response reported in the study by Smith et al. (1999) in which ADFI was decreased (from 73 to 91 kg) in treatments without added fat when added dietary fat was included in the previous phase; however, the decrease in ADG as a result of the decrease in ADFI was not observed in this experiment. The carryover responses in energy intake mimicked those in ADFI. However, during phases 2 (45 to 70 kg) and 3 (70 to 90 kg), ADFI was not affected by dietary fat, whereas energy intake was increased when fat was added to the diet. The increase in energy intake resulted in an increase in ADG similar to the results from Bikker et al. (1996b), who observed that from 45 to 85 kg, as energy intake increased, growth rates were improved.

Feed efficiency was improved in all phases by fat addition, as observed in Exp. 1. The carryover effect found from 90 to 115 kg indicates that G:F was increased during this phase for pigs previously fed diets containing added fat from 70 to 90 kg. These pigs also did not have the reduced carcass leanness found for pigs fed fat throughout all four phases. Thus, by feeding fat in the first three phases, performance was maximized in phase 4, but carcass value was not decreased due to increased backfat depth or decreased lean percentage.

Implications

These results indicate that adding 6% fat to corn-soybean meal diets consistently improves feed efficiency of pigs in all phases of growth under commercial conditions. However, improvements in growth rate only occur when pigs are in an energy-dependent state of growth. Also, positive carryover effects on growth and feed efficiency exist during later periods of growth when added dietary fat is included in the previous phase. Therefore, the economic value of added fat is higher during the earlier phases than during the later phases of the growing-finishing period.

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