Effects of diet form and type on growth performance, carcass yield, and iodine value of finishing pigs[1]

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ABSTRACT: Two experiments were conducted to determine the effects of pelleting, diet type (fat and fiber level), and withdrawal of dietary fiber and fat before marketing on growth performance, carcass yield, and carcass fat iodine value (IV) of finishing pigs. Each experiment used 288 pigs (initially 49.6 and 48.5 kg BW, respectively) with 6 dietary treatments arranged as 2 × 3 factorials. In Exp. 1, main effects were diet form (meal vs. pellet) and diet regimen. Diet regimens were 1) a low-fiber, low-fat (corn–soybean meal) diet from d 0 to 81, 2) a high-fiber, high-fat (30% dried distillers grains with solubles [DDGS] and 19% wheat middlings [midds]) diet from d 0 to 64 followed by the low-fiber, low-fat diet from d 64 to 81 (fiber and fat withdrawal), and 3) the high-fiber, high-fat diet fed from d 0 to 81. Pigs fed pelleted diets had increased ($P < 0.05$) ADG and G:F compared with those fed meal diets. Pigs fed pelleted diets had increased belly fat IV (2.9 mg/g) compared with those fed meal diets, with a greater increase when fed high-fiber, high-fat diets throughout the entire study (interaction, $P < 0.05$). Pigs fed the low-fiber, low-fat diet throughout had increased ($P < 0.001$) G:F compared with pigs fed the other 2 treatments. Pigs fed low-fiber, low-fat diets throughout the study or pigs withdrawn from high-fiber, high-fat diets had increased ($P < 0.001$) carcass yield compared with pigs fed high-fiber, high-fat diets throughout. In Exp. 2, treatment main effects were diet form (meal vs. pellet) and diet type (corn–soybean meal–based control, the control with 30% DDGS and 19% midds, or the control diet with 3% corn oil). The diet containing corn oil was calculated to produce carcass fat IV similar to diets containing DDGS and midds. Overall, pigs fed pelleted diets had increased ($P < 0.05$) ADG, G:F, and belly fat IV (1.3 mg/g) compared with those fed meal diets. Pigs fed the diets containing DDGS and midds had decreased ($P < 0.05$) ADG, carcass yield, and HCW compared with pigs fed the control or corn oil diets and decreased ($P < 0.001$) G:F compared with pigs fed added corn oil. Belly IV was greatest ($P < 0.001$) for pigs fed diets with DDGS and midds and lowest for pigs fed the control diet, with pigs fed the corn oil diets intermediate. In conclusion, pelleting diets improves pig ADG (approximately 3%) and G:F (approximately 6%); however, a novel finding of this study is that pelleting diets fed to finishing pigs also increases belly fat IV.

Key words: carcass yield, corn oil, distillers dried grains with solubles, finishing pig, pelleting

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INTRODUCTION

Studies have observed that up to 30% dried distillers grains with solubles (**DDGS**) can be fed without negative effects on growth performance (Widmer et al., 2007; Stein and Shurson, 2009; Xu et al., 2010). When DDGS were combined with wheat middlings (**midds**), however, Salyer et al. (2012) observed linear decreases in ADG and G:F as midds were added at 0%, 10%, or 20%.

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In addition, feeding high levels of DDGS, midds, or the combination of both reduces carcass yield of finishing pigs (Linneen et al., 2008; Salyer et al., 2012). This is due to increased large intestinal weights caused by the high-fiber component of the ingredients (Asmus et al., 2014). Along with the dietary fiber component from DDGS and midds, the oil content, particularly C18:2 fatty acids, also increases (NRC, 2012). Iodine value (**IV**), a measure of unsaturated fatty acids (**UFA**), is 1 method used by packers to assess fat quality in pork. Feeding ingredients high in UFA increases carcass fat IV (Benz et al., 2011), thus producing less desirable product for the meat packing industry (McClelland et al., 2012). Reducing or withdrawing added DDGS and midds before marketing can mitigate some of the negative effects on carcass yield and carcass fat IV (Gaines et al., 2007; Asmus et al., 2014; Coble et al., 2014).

The beneficial effects of pelleting swine diets on growth performance of finishing pigs also have been documented, including increased BW gain and improved feed efficiency (Baird, 1973; Wondra et al., 1995), but most of the previous pelleting research has evaluated corn–soybean meal–based diets with limited inclusion of by-products. In addition, to our knowledge, the effects of pelleting on FA profile and IV of carcass fat have not been reported. Therefore, the objective of these trials was to determine the effects of diet type and form on growth performance, carcass yield, and carcass fat IV of finishing pigs.

MATERIALS AND METHODS

All experimental procedures and animal care were approved by the Kansas State University Institutional Animal Care and Use Committee.

General

Experiments 1 and 2 each used a total of 288 finishing pigs (327 × 1050, PIC, Hendersonville, TN) initially 49.6 and 48.5 kg BW, respectively. Pigs were housed in a totally enclosed, environmentally regulated, mechanically ventilated barn containing 36 pens (2.44 × 3.05 m). The pens had adjustable gates facing the alleyway and allowed 0.93 m^2/pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder (Farmweld, Teutopolis, IL) with 2 eating spaces located in the fence line. Pens were located over a completely slatted concrete floor with a 1.20-m pit underneath for manure storage. All pigs were provided ad libitum access to feed and water.

Each experiment was arranged as a 2 × 3 factorial. Pens were randomly allotted to 1 of 6 experimental treatments with 6 pens per treatment and 8 pigs per pen (4 barrows and 4 gilts per pen). Pigs and feeders were weighed approximately every 2 wk to calculate ADG, ADFI, G:F, and caloric efficiency on a ME and NE basis. Diets for both experiments were prepared and pelleted at a commercial feed mill in Beloit, KS (Hubbard Feeds Inc., Mankato, MN). All pelleted diets were processed with a Sprout Waldron Pellet Mill (model Ace 501; Sprout, Waldron & Company, Inc., Muncy, PA) equipped with a 4.37-mm-diam. die. Before pelleting, diets were conditioned with steam at 71°C for approximately 20 s. A single batch of meal feed was prepared; half was fed as such, and half was pelleted. Diets were delivered to feeders using a computerized feeding system (FeedPro, Feedlogic Corp., Willmar, MN) that recorded all feed additions. Feed samples were taken at the feeder during each phase. All diets were analyzed for moisture (method 934.01; AOAC, 2006), CP (method 990.03; AOAC, 2006), ether extract (method 920.39 A; AOAC, 2006), crude fiber (method 978.10; AOAC, 2006), ADF, and NDF. Pellet durability index (**PDI**) was determined using the standard tumbling-box technique (standard S269.4; American Society for Agricultural Engineers [**ASAE**], 1996), and modified PDI was done by adding 5 hexagonal nuts (1.27 cm) before tumbling. Percentage of fines (ASAE, 1987) was also measured in duplicate for all pelleted diets, with fines characterized as material that would pass through a #6 sieve (3,360-μm openings). All pellet quality measurements were analyzed at the K-State O. H. Kruse Feed Technology Innovation Center.

At the end of each trial, pigs were individually tattooed in sequential order to allow for carcass data collection at a commercial packing plant and data retrieval by pig. Hot carcass weights were measured immediately after evisceration and were used to calculate percentage yield by dividing HCW at the plant by live weight at the farm before transport. All carcass fat samples were collected from the pig's left side. For both experiments, belly fat samples were collected from the ventral side of the belly along the navel edge between the 10th and the 12th ribs of each pig. In Exp. 2, fat samples were also collected from the shoulder of each pig approximately 5 cm dorsal to the medial ridge of the scapula. All fat samples were immediately frozen after collection and remained frozen until preparation for FA analysis could be conducted. Fat samples were thawed, and adipose tissue was isolated by removing the skin and lean tissue. Samples were then analyzed for FA profiles using gas chromatography as described in detail by Asmus et al. (2014). Iodine value was calculated using the following equation (American Oil Chemists' Society, 1998): $IV = [C16:1] \times 0.95 + [C18:1] \times 0.86 + [C18:2] \times 1.732 + [C18:3] \times 2.616 + [C20:1] \times 0.785 + [C22:1] \times 0.723$.

Table 1. Composition of diets, Exp. 1 (as-fed basis)[1]

	Phase 1		Phase 2		Phase 3		Phase 4	
Item	Low fiber	High fiber	Low fiber	High fiber	Low fiber	High fiber	Low fiber	Highfiber
Ingredient, %								
Corn	73.71	34.88	78.93	39.99	82.65	43.56	84.97	45.79
Soybean meal, 46.5% CP	23.80	13.74	18.84	8.71	15.32	5.20	13.15	3.04
Dried distillers grains with solubles	—	30.00	—	30.00	—	30.00	—	30.00
Wheat middlings	—	19.00	—	19.00	—	19.00	—	19.00
Monocalcium P, 21% P	0.45	—	0.35	—	0.25	—	0.20	—
Limestone	1.05	1.30	1.00	1.28	0.98	1.29	0.93	1.28
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.15	0.15	0.13	0.13	0.10	0.10	0.08	0.08
Trace mineral premix[3]	0.15	0.15	0.13	0.13	0.10	0.10	0.08	0.08
L-Lys·HCl	0.170	0.310	0.150	0.293	0.135	0.278	0.128	0.270
DL-Met	0.020	—	—	—	—	—	—	—
L-Thr	0.025	—	0.010	—	—	—	—	—
Phytase[4]	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
Standardized ileal digestible amino acids, %								
Lys	0.93	0.93	0.79	0.79	0.69	0.69	0.63	0.63
Ile:Lys	69	72	70	74	72	76	73	78
Met:Lys	30	34	30	37	32	40	33	43
Met + Cys:Lys	59	70	62	77	66	83	69	88
Thr:Lys	63	66	63	69	64	72	66	74
Trp:Lys	19	19	19	19	19	19	19	19
Val:Lys	78	88	81	94	85	99	87	103
Total Lys, %	1.04	1.09	0.89	0.94	0.78	0.83	0.72	0.77
ME, kcal/kg	3,296	3,233	3,307	3,240	3,316	3,245	3,324	3,249
NE, kcal/kg	2,474	2,333	2,507	2,365	2,533	2,386	2,549	2,400
CP, %	17.5	20.8	15.6	18.9	14.3	17.6	13.5	16.7
Ca, %	0.59	0.58	0.53	0.56	0.49	0.55	0.46	0.54
P, %	0.47	0.58	0.42	0.56	0.39	0.55	0.37	0.54
Available P, %	0.27	0.39	0.25	0.38	0.22	0.38	0.21	0.37

[1]Phase 1 diets were fed from d 0 to 15, phase 2 from d 15 to 40, phase 3 from d 40 to 64, and phase 4 from d 64 to 81. Each diet was fed in either meal or pellet form.

[2]Provided per kilogram of premix: 4,409,200 IU vitamin A, 551,150 IU vitamin D_3, 17,637 IU vitamin E, 1,764 mg vitamin K, 3,307 mg riboflavin, 11,023 mg pantothenic acid, 19,841 mg niacin, and 15.4 mg vitamin B_{12}.

[3]Provided per kilogram of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulfate, 11g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[4]Phyzyme 600 (Danisco Animal Nutrition, St. Louis, MO) provided 780 phytase units (FTU)/kg, with a release of 0.11% available P.

Experiment 1

An 81-d trial was conducted to determine the effects of diet form and fiber withdrawal on growth performance, carcass yield, and carcass fat IV of finishing pigs. Treatment main effects included diet form (meal or pellet) and diet regimen. The 3 diet regimens were 1) low fiber, low fat (corn–soybean meal) from d 0 to 81, 2) high fiber, high fat (30% DDGS and 19% midds) from d 0 to 64 followed by low fiber, low fat from d 64 to 81 (fiber and fat withdrawal), and 3) high fiber, high fat from d 0 to 81 (Table 1). Diets were fed in 4 phases from d 0 to 14, 14 to 40, 40 to 64, and 64 to 81. Diets within phase were formulated to contain equal amounts of standardized ileal digestible (**SID**) Lys with 0.93, 0.79, 0.69, and 0.63 SID Lys for phases 1, 2, 3, and 4, respectively. Thus, diets contained different SID Lys:energy ratios as dietary energy was not held constant.

Experiment 2

An 87-d trial was conducted to determine the effects of diet form and type on growth performance, carcass yield, and carcass fat IV of finishing pigs. Treatments were arranged in a 2 × 3 factorial with the main effects of diet form and type. The 2 diet forms used were meal and pellet. The 3 dietary types were 1) corn–soybean meal–based control, 2) control with

Table 2. Composition of phase 1 and 2 diets, Exp. 2 (as-fed basis)

	Phase 1[1]			Phase 2[2]		
Item	Control	DDGS + midds	Corn oil	Control	DDGS + midds	Corn oil
Ingredient, %						
Corn	72.01	33.03	68.84	77.57	37.46	74.25
Soybean meal, 46.5% CP	25.56	15.70	25.64	20.17	11.36	20.40
DDGS	—	30.00	—	—	30.00	—
Wheat middlings	—	19.00	—	—	19.00	—
Corn oil	—	—	3.00	—	—	3.00
Monocalcium P, 21% P	0.45	—	0.52	0.37	—	0.44
Limestone	1.05	1.30	1.05	1.00	1.28	1.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.150	0.150	0.150	0.125	0.125	0.125
Trace mineral premix[4]	0.150	0.150	0.150	0.125	0.125	0.125
L-Lys·HCl	0.220	0.310	0.225	0.235	0.293	0.235
Met hydroxyl analog	0.020	—	0.028	0.013	—	0.015
L-Thr	0.030	—	0.040	0.035	—	0.040
Phytase[5]	0.012	0.012	0.012	0.015	0.015	0.015
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Standardized ileal digestible amino acids, %						
Lys	0.98	0.98	0.98	0.86	0.86	0.86
Ile:Lys	67	71	66	65	72	65
Met:Lys	28	33	29	29	35	29
Met + Cys:Lys	55	62	55	56	67	56
Thr:Lys	60	62	61	61	63	61
Trp:Lys	19	19	19	18	18	18
Val:Lys	74	85	73	74	88	73
Total Lys, %	1.11	1.19	1.11	0.98	1.05	0.97
ME, kcal/kg	3,298	3,234	3,452	3,309	3,241	3,463
NE, kcal/kg	2,466	2,325	2,610	2,502	2,352	2,646
CP, %	18.4	21.7	18.1	16.3	20.0	16.1
Ca, %	0.55	0.57	0.56	0.50	0.55	0.52
P, %	0.47	0.56	0.47	0.42	0.54	0.43
Available P, %	0.29	0.37	0.30	0.26	0.37	0.28

[1]Phase 1 diets were fed from d 0 to 21. DDGS = dried distillers grains with solubles; midds = wheat middlings.

[2]Phase 2 diets were fed from d 21 to 45.

[3]Provided per kilogram of premix: 4,409,200 IU vitamin A, 551,150 IU vitamin D_3, 17,637 IU vitamin E, 1,764 mg vitamin K, 3,307 mg riboflavin, 11,023 mg pantothenic acid, 19,841 mg niacin, and 15.4 mg vitamin B_{12}.

[4]Provided per kilogram of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulfate, 11g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[5]Natuphos 2500 (BASF Corp., Mt. Olive, NJ) provided 300 phytase units (FTU)/kg, with a release of 0.10% available P.

Table 3. Composition of phase 3 and 4 diets, Exp. 2 (as-fed basis)

	Phase 3[1]			Phase 4[2]		
Item	Control	DDGS + midds	Corn oil	Control	DDGS + midds	corn oil
Ingredient, %						
Corn	81.04	40.70	77.72	83.98	43.80	80.62
Soybean meal (46.5% CP)	16.81	8.16	17.04	13.86	5.13	14.17
DDGS	—	30.00	—	—	30.00	—
Wheat middlings	—	19.00	—	—	19.00	—
Corn oil	—	—	3.00	—	—	3.00
Monocalcium P, 21% P	0.34	—	0.42	0.45	—	0.49
Limestone	0.98	1.29	0.98	0.93	1.28	0.93
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.100	0.100	0.100	0.075	0.075	0.075
Trace mineral premix[4]	0.100	0.100	0.100	0.075	0.075	0.075
L-Lys·HCl	0.225	0.278	0.225	0.215	0.270	0.213
Met hydroxyl analog	0.010	—	0.010	—	—	0.010
L-Thr	0.038	—	0.043	0.050	—	0.055
Phytase[5]	0.018	0.018	0.018	0.021	0.021	0.021
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Standardized ileal digestible amino acids, %						
Lys	0.77	0.77	0.77	0.69	0.69	0.69
Ile:Lys	66	74	65	66	75	66
Met:Lys	30	37	29	30	40	31
Met + Cys:Lys	59	71	58	60	75	61
Thr:Lys	62	65	62	65	67	66
Trp:Lys	18	18	18	18	18	18
Val:Lys	75	92	74	77	96	76
Total Lys, %	0.88	0.96	0.88	0.79	0.87	0.79
ME, kcal/kg	3,316	3,245	3,470	3,318	3,250	3,472
NE, kcal/kg	2,524	2,372	2,668	2,542	2,392	2,685
CP, %	14.9	18.7	14.8	13.8	17.5	13.6
Ca, %	0.48	0.54	0.49	0.47	0.53	0.48
P, %	0.40	0.53	0.41	0.41	0.52	0.41
Available P, %	0.25	0.36	0.27	0.27	0.36	0.28

[1]Phase 3 diets were fed from d 45 to 70. DDGS = dried distillers grains with solubles; midds = wheat middlings.

[2]Phase 4 diets were fed from d 70 to 87.

[3]Provided per kilogram of premix: 4,409,200 IU vitamin A, 551,150 IU vitamin D_3, 17,637 IU vitamin E, 1,764 mg vitamin K, 3,307 mg riboflavin, 11,023 mg pantothenic acid, 19,841 mg niacin, and 15.4 mg vitamin B_{12}.

[4]Provided per kilogram of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulfate, 11g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[5]Natuphos 2500 (BASF Corp., Mt. Olive, NJ) provided 300 phytase units (FTU)/kg, with a release of 0.10% available P.

30% DDGS and 19% midds, and 3) control with 3% corn oil (Tables 2 and 3). The corn–soybean meal–based control provided a baseline, whereas the diet containing 30% DDGS and 19% midds was the previously established diet from Exp. 1 that allowed for a predic increase in carcass fat IV. Extracted corn oil was used in the third treatment to compare it to the endogenous corn oil present in the DDGS. The level of 3% corn oil was selected on the basis of research conducted by Benz et al. (2011) with soybean oil in an

Table 4. Chemical analysis of diets, Exp. 1[1]

	Phase 1[2]				Phase 2[3]			
	Meal		Pellet		Meal		Pellet	
Item	Low fiber	High fiber	Low fiber	High fiber	Low fiber	High fiber	Low fiber	High fiber
DM, %	89.58	89.96	89.71	89.06	90.58	88.60	90.07	88.54
CP, %	18.1	20.6	18.4	22.1	16.8	21.3	17.0	20.8
ADF, %	3.1	7.1	3.1	5.9	2.5	7.0	1.9	4.9
NDF, %	5.7	14.5	6	14.2	6.0	15.5	5.9	13.9
Crude fiber, %	1.8	4.0	1.9	3.5	1.7	4.3	1.8	3.5
Ether extract, %	1.6	3.7	1.7	4.0	2.3	4.7	2.0	4.5
Ca, %	0.55	0.63	0.56	0.66	0.39	0.60	0.42	0.61
P, %	0.46	0.65	0.47	0.63	0.45	0.69	0.43	0.59

[1]A composite sample consisting of 6 subsamples was used for analysis.

[2]Phase 1 diets were fed from d 0 to 15.

[3]Phase 2 diets were fed from d 15 to 40.

Table 5. Chemical analysis of diets, Exp. 1[1]

	Phase 3[2]				Phase 4[3]			
	Meal		Pellet		Meal		Pellet	
Item	Low fiber	High fiber	Low fiber	High fiber	Low fiber	High fiber	Low fiber	High fiber
DM, %	88.54	89.24	88.91	88.42	88.58	89.17	89.14	91.40
CP, %	14.9	19.4	15.0	19.5	14.0	17.8	13.4	17.7
ADF, %	2.3	6.1	2.6	6.2	2.4	6.3	2.2	6.0
NDF, %	6.2	16.9	7.2	16.5	7.1	16.1	6.2	16.0
Crude fiber, %	2.0	4.1	1.8	4.3	1.8	4.5	1.8	4.5
Ether extract, %	1.9	4.5	2.4	3.3	2.3	4.5	2.2	5.1
Ca, %	0.45	0.46	0.43	0.57	0.30	0.47	0.40	0.54
P, %	0.47	0.66	0.43	0.58	0.38	0.65	0.36	0.63

[1]A composite sample consisting of 6 subsamples was used for analysis.

[2]Phase 3 diets were fed from d 40 to 64.

[3]Phase 4 diets were fed from d 64 to 81.

effort to obtain carcass fat IV similar to that of pigs fed the diet containing DDGS and midds. Diets were fed in 4 phases from d 0 to 21, 21 to 45, 45 to 70, and 70 to 87. Diets within phase were formulated to contain equal amounts of SID Lys with 0.98, 0.86, 0.77, and 0.69 SID Lys for phases 1, 2, 3, and 4, respectively.

Statistical Analysis

Experimental data for both trials were analyzed using ANOVA as a 2 × 3 factorial using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Pen was the experimental unit for all data analysis. For HCW, carcass yield, and carcass fat IV, measurements were collected for each pig; then pen means were calculated and used in the model. Experiment 1 included main effects of 2 diet forms and 3 diet regimens and their interaction as fixed effects, and Exp. 2 included main effects of 2 diet forms and 3 diet types and their interactions. Differences between treatments were determined using least squares means with results considered significant at $P \leq 0.05$ and a trend at $P \leq 0.10$.

RESULTS

Experiment 1

Chemical Analysis and Pellet Quality Measurements. Analysis of diets revealed that as expected, the inclusion of dietary DDGS and midds increased ADF, NDF, crude fiber, and ether extract (Tables 4 and 5). Standard PDI was greater than 90% during all phases for pelleted diets (Table 6). Percentage of fines was low for all diets and phases at less than 10% fines.

Growth Performance and Carcass Yield. No diet form × diet regimen interactions ($P > 0.14$) were observed for growth performance during any of the dietary phases or for the overall trial (Table 7). From d 0 to 64, ADG did not differ among pigs fed different diet forms; however, pigs fed meal diets had increased ($P < 0.05$) ADFI and poorer ($P < 0.05$) G:F than pigs fed pelleted diets. Diet type level did not influence ADG, but pigs fed low-fiber, low-fat diets from d 0 to 64 had decreased

Table 6. Analysis of pellet quality, Exp. 1[1]

	Fiber level	
Item	Low[2]	High[3]
Standard pellet durability index,[4] %		
Phase 1	91.0	92.7
Phase 2	90.1	96.2
Phase 3	92.9	95.9
Phase 4	94.9	91.4
Modified pellet durability index[5]		
Phase 1	87.9	89.4
Phase 2	86.3	92.7
Phase 3	89.5	93.8
Phase 4	92.4	88.8
Fines, %		
Phase 1	7.6	7.3
Phase 2	9.0	7.4
Phase 3	8.0	8.4
Phase 4	7.9	8.1

[1]A representative feed sample was taken at the feeder during each phase and analyzed in duplicate for each pellet quality measurement.

[2]Refers to diet with 0% dried distillers grains with solubles (DDGS) and 0% wheat middlings (midds).

[3]Refers to diet with 30% DDGS and 19% midds.

[4]Pellet durability index was determined using the standard tumbling-box technique.

[5]Procedure was altered by adding 5 hexagonal nuts before tumbling.

Table 7. Effects of diet regimen and diet form on finishing pig growth performance, Exp. 1[1]

	Diet form							Probability *P*		
	Meal[2]			Pellet[2]						
Item	Low, low	High, low	High, high	Low, low	High, low	High, high	SEM	Diet form × regimen	Meal vs. pellet	Diet regimen
d 0 to 64										
ADG, kg	0.95	0.97	0.96	0.97	0.98	0.99	0.022	0.925	0.273	0.636
ADFI, kg	2.47	2.63	2.65	2.41	2.49	2.52	0.055	0.758	0.016	0.012
G:F	0.386	0.368	0.362	0.405	0.393	0.391	0.010	0.523	0.001	0.001
d 64 to 81										
ADG, kg	0.93	0.97	0.88	1.02	1.03	0.97	0.032	0.886	0.005	0.026
ADFI, kg	2.93	3.26	3.22	3.15	3.38	3.16	0.069	0.135	0.100	0.001
G:F	0.317	0.296	0.273	0.322	0.303	0.306	0.009	0.246	0.058	0.006
d 0 to 81										
ADG, kg	0.95	0.97	0.94	0.98	0.99	0.98	0.017	0.829	0.029	0.354
ADFI, kg	2.56	2.77	2.77	2.56	2.67	2.66	0.054	0.568	0.116	0.006
G:F	0.369	0.350	0.341	0.384	0.370	0.370	0.005	0.192	0.001	0.001
Caloric efficiency, kcal/kg gain										
ME	8.97	9.32	9.66	8.63	8.83	8.88	0.121	0.193	0.001	0.002
NE	6.82	6.89	6.98	6.56	6.54	6.42	0.088	0.218	0.001	0.965
BW, kg										
d 0	49.7	49.4	49.8	49.5	49.9	49.3	1.327	0.913	0.972	0.930
d 64	111.0	111.4	111.2	112.5	112.7	112.4	1.869	0.996	0.371	0.882
d 81	126.7	127.8	126.1	130.4	130.1	128.9	1.885	0.940	0.066	0.436
Carcass yield, %	75.11	74.66	74.11	75.03	74.85	73.35	0.239	0.876	0.277	0.001
HCW, kg	95.3	95.4	93.5	97.9	97.5	94.7	1.314	0.131	0.080	0.105

[1]A total of 288 pigs (PIC 327 × 1050, initially 49.6 kg BW) were used in an 81-d trial with 6 pens per treatment and 8 pigs per pen.

[2]Low refers to diet with 0% dried distillers grains with solubles (DDGS) and 0% wheat middlings (midds); high refers to diet with 30% DDGS and 19% midds. The first "high" or "low" designation indicates the amount of fiber fed from d 0 to 64; the second indicates the amount of fiber fed from d 64 to 81.

($P < 0.05$) ADFI and increased ($P < 0.05$) G:F compared with pigs fed high-fiber, high-fat diets during this period.

From d 64 to 81, pigs fed pelleted diets had increased ($P < 0.05$) ADG and tended to have increased ($P = 0.10$) ADFI compared with pigs fed meal diets. Feeding pelleted diets also tended to increase ($P < 0.10$) G:F. Pigs previously fed high-fiber, high-fat diets and then switched to low-fiber, low-fat diets during this phase had increased ($P < 0.05$) ADG compared with pigs maintained on the high-fiber, high-fat diets. Pigs fed the low-fiber, low-fat diets throughout the trial had intermediate ADG. Pigs previously fed high-fiber, high-fat diets and switched to the low-fiber, low-fat diet had increased ($P < 0.05$) ADFI compared with pigs fed low-fiber, low-fat or high-fiber, high-fat diets throughout the trial. Pigs fed low-fiber, low-fat diets throughout the trial had increased ($P < 0.05$) G:F compared with pigs fed high-fiber, high-fat diets throughout, and pigs that were withdrawn from the high-fiber, high-fat diet were intermediate.

Overall (d 0 to 81), there was no difference in ADFI between pigs fed the different diet forms. Pigs fed pelleted diets tended ($P < 0.10$) to have increased final BW and HCW compared with pigs fed meal diets, but diet form did not influence carcass yield. Diet regimen did not influence ADG for the overall trial, but pigs fed low-fiber, low-fat diets throughout the trial had decreased ($P < 0.05$) ADFI and improved ($P < 0.05$) G:F compared with pigs on the high-fiber, high-fat withdrawal or pigs fed the high-fiber, high-fat regimen throughout. Caloric efficiency was improved ($P < 0.05$) on an ME and NE basis when diets were pelleted. Feeding the high-fiber, high-fat regimen resulted in poorer ($P < 0.05$) caloric efficiency on an ME basis; however, diet regimen did not influence caloric efficiency on a NE basis. Diet regimen did not affect final BW or HCW, but pigs fed high-fiber, high-fat diets throughout the trial had decreased ($P < 0.05$) carcass yield compared with pigs fed low-fiber, low-fat diets or those withdrawn from high-fiber, high-fat diets on d 64. Removing high-fiber ingredients (DDGS and midds) from the diet before harvest improved carcass yield and returned carcass weights to values similar to that of control pigs fed corn–soybean meal–based diets throughout the trial.

Belly Fatty Acid Composition. Interactive effects between diet form and diet regimen were detected ($P < 0.05$) for palmitic (C16:0) and linoleic (C18:2n6c)

Table 8. Effects of diet regimen and diet form on finishing pig belly fatty acid profile, Exp. 1[1]

	Diet form									
	Meal[2]			Pellet[2]				Probability *P*		
Item	Low, low	High, low	High, high	Low, low	High, low	High, high	SEM	Diet form × regimen	Meal vs. pellet	Diet regimen
Myristic acid (C14:0), %	1.47	1.39	1.36	1.44	1.31	1.29	0.018	0.588	0.001	0.001
Palmitic acid (C16:0), %	23.91	22.49	21.87	23.68	21.67	21.04	0.130	0.049	0.001	0.001
Palmitoleic acid (C16:1), %	3.30	3.06	2.96	3.03	2.66	2.62	0.061	0.805	0.001	0.001
Margaric acid (C17:0), %	0.35	0.39	0.43	0.33	0.36	0.38	0.014	0.449	0.002	0.001
Stearic acid (C18:0), %	10.61	9.44	8.94	10.79	9.21	8.64	0.114	0.073	0.187	0.001
Oleic acid (C18:1n9c), %	39.45	37.84	36.73	38.71	36.59	35.73	0.214	0.652	0.001	0.001
Vaccenic acid (C18:1n7), %	4.27	3.95	3.76	4.02	3.57	3.47	0.051	0.865	0.001	0.001
Linoleic acid (C18:2n6c), %	12.89	17.22	19.57	14.25	20.38	22.51	0.290	0.012	0.001	0.001
Total C18:2 fatty acids,[3] %	13.05	17.41	19.75	14.38	20.52	22.64	0.290	0.012	0.001	0.001
α-Linolenic acid (C18:3n3), %	0.58	0.68	0.74	0.63	0.80	0.84	0.014	0.163	0.001	0.001
Arachidic acid (C20:0), %	0.22	0.22	0.21	0.23	0.22	0.21	0.004	0.535	0.572	0.001
Eicosenoic acid (C20:1), %	0.65	0.67	0.66	0.67	0.66	0.63	0.015	0.333	0.580	0.364
Eicosadienoic acid (C20:2), %	0.59	0.78	0.85	0.65	0.90	0.95	0.012	0.153	0.001	0.001
Arachidonic acid (C20:4n6), %	0.25	0.29	0.30	0.24	0.28	0.29	0.006	0.839	0.154	0.001
Other fatty acids, %	1.30	1.42	1.46	1.22	1.26	1.29	0.018	0.049	0.001	0.001
Total SFA,[4] %	36.94	34.29	33.18	36.82	33.12	31.90	0.208	0.011	0.001	0.001
Total MUFA,[5] %	48.25	46.16	44.76	46.95	43.99	42.96	0.286	0.559	0.001	0.001
Total PUFA,[6] %	14.80	19.55	22.06	16.23	22.89	25.15	0.318	0.018	0.001	0.001
UFA:SFA[7]	1.71	1.92	2.02	1.72	2.03	2.14	0.018	0.005	0.001	0.001
PUFA:SFA[8]	0.40	0.57	0.67	0.44	0.69	0.79	0.012	0.001	0.001	0.001
Iodine value,[9] mg/g	65.7	71.7	74.7	67.0	75.5	78.4	0.378	0.003	0.001	0.001

[1]All items calculated as a percentage of the total fatty acid content. Belly fat samples were collected from the ventral side of the belly along the navel edge between the 10th and the 12th ribs.

[2]Low refers to diet with 0% dried distillers grains with solubles (DDGS) and 0% wheat middlings (midds); high refers to diet with 30% DDGS and 19% midds. The first "high" or "low" designation indicates the amount of fiber fed from d 0 to 64; the second indicates the amount of fiber fed from d 64 to 81.

[3]Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].

[4]Total SFA = [% C10:0] + [% C11:0] + [% C12:0] + [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].

[5]Total MUFA = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].

[6]Total PUFA = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c,11t] + [% C18:2 10t,12c] + [% C18:2 9c,11c] + [% C18:2 9t,11t] + [% C18:3n6] + [% C18:3n3] + [% C20:2] + [% C20:3n6] + [% C20:4n6] + [% C20:5n3] + [% C22:5n3] + [% C22:5n6].

[7]UFA:SFA ratio = [total MUFA + total PUFA]/total SFA.

[8]PUFA:SFA ratio = total PUFA/total SFA.

[9]Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785 + [% C22:1] × 0.723.

acid concentrations (Table 8). Pelleting decreased palmitic and increased linoleic acid by a greater magnitude when the diet contained high fiber and fat contents than when the diet was low in fiber and fat. Palmitic and total C18:2 fatty acids account for the greatest portions of SFA and PUFA, respectively. As a result, there were also interactions ($P < 0.05$) for belly fat IV, total SFA, total PUFA, UFA:SFA ratio, PUFA:SFA ratio, and belly fat IV. Pelleting the diets also increased belly fat IV and UFA, with the magnitude of response being greater when the high-fiber diets were pelleted compared with the low-fiber diets. On average, pelleting the diets increased belly fat IV by 2.9 mg/g.

Feeding pelleted diets reduced ($P < 0.05$) myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), margaric (C17:0), oleic (C18:1n9c), and vaccenic (C18:1n7) fatty acids; however, it increased ($P < 0.05$) linoleic (C18:2n6c), α-linolenic (C18:3n3), eicosadienoic (C20:2), and total C18:2 fatty acids (8). As a result, total PUFA and belly fat IV increased ($P < 0.05$), whereas total SFA, MUFA, and all other fatty acids decreased ($P < 0.05$) when pigs were fed pelleted diets. There were no differences ($P > 0.10$) in stearic (C18:0), arachidic (20:0), eicosenoic (20:1), and arachidonic (C20:4n6) fatty acids between pigs fed the different diet forms.

Compared with pigs fed high-fat, high-fiber diets throughout the trial, pigs fed low-fiber, low-fat regimens throughout the trial had increased ($P < 0.05$) C16:0, C18:0, C18:1n9c, C18:1n7, total SFA, and total MUFA concentrations, with those fed the withdrawal

Table 9. Chemical analysis of diets, Exp. 2[1]

	Phase 1[2]						Phase 2[3]					
	Meal			Pellet			Meal			Pellet		
Item	Control	DDGS + midds	Corn oil	Control	DDGS + Midds	Corn oil	Control	DDGS + midds	Corn oil	Control	DDGS + midds	Corn oil
DM, %	89.47	90.73	89.62	89.18	88.94	89.33	89.60	90.63	89.47	89.46	88.64	89.13
CP, %	17.7	18.4	18.0	18.8	23.0	18.1	18.1	18.6	17.4	16.9	21.6	17.0
ADF, %	2.7	7.1	2.6	3	7.3	3.1	3.2	7.3	3.3	2.9	6.4	3.2
NDF, %	7.6	17.7	6.6	6.7	16.6	6.6	5.9	18.0	6.7	5.1	14.0	5.3
Crude fiber, %	2.0	4.7	2.0	1.8	4.5	2.0	2.1	4.8	2.1	1.8	4.0	2.0
Ether extract, %	1.6	4.3	3.5	1.4	3.4	3.7	1.5	4.3	3.7	1.5	3.2	3.1
Ca, %	0.98	0.45	0.83	0.58	0.62	0.64	0.62	0.58	0.54	0.65	0.60	0.53
P, %	0.49	0.65	0.51	0.48	0.66	0.49	0.46	0.66	0.44	0.44	0.62	0.42

[1]A composite sample consisting of 6 subsamples was used for analysis. DDGS = dried distillers grains with solubles; midds = wheat middlings.

[2]Phase 1 diets were fed from d 0 to 21.

[3]Phase 2 diets were fed from d 21 to 45.

regimen intermediate ($P < 0.05$). Pigs fed the low-fiber, low-fat diet had decreased ($P < 0.05$) C18:2n6C, C18:3n3, C20:2, C20:4n6, total C18:2, PUFA, and belly fat IV compared with those fed high-fiber, high-fat diets, with those on the withdrawal regimen intermediate ($P < 0.05$).

Regardless of withdrawal, pigs fed high-fiber, high-fat diets during any period of the experiment had decreased ($P < 0.05$) C14:0 and C16:1 concentrations and increased ($P < 0.05$) C17:0 concentrations compared with pigs fed low-fiber, low-fat diets for the entire trial. Feeding high-fiber, high-fat diets throughout the experiment decreased ($P < 0.05$) C20:0 concentrations compared with the other 2 regimens. No differences were detected in C20:1 among pigs fed the different diet regimens.

Experiment 2

Chemical Analysis and Pellet Quality Measurements. Analysis of diets revealed that as expected, the inclusion of dietary DDGS and midds increased ADF, NDF, crude fiber, and ether extract (Tables 9 and 10). In addition, ether extract increased because of the inclusion of corn oil, which was also expected. Standard PDI was greater than 88% during all phases for pelleted diets, with modified PDI ranging from 82.5% to 87.5% (Table 11). Percentage of fines was low for all diets and phases, ranging from approximately 7% to 14% fines.

Growth Performance and Carcass Yield. No diet form × diet type interactions were observed for growth performance, HCW, or carcass yield for the overall trial (Table 12). Overall (d 0 to 87), pigs fed pelleted diets had increased ($P < 0.05$) ADG, decreased ($P < 0.05$) ADFI, and improved ($P < 0.05$) G:F and caloric efficiency compared with pigs fed meal diets (12). Pigs fed pelleted diets tended ($P < 0.10$) to have in-

Table 10. Chemical analysis of diets, Exp. 2[1]

	Phase 3[2]						Phase 4[3]					
	Meal			Pellet			Meal			Pellet		
Item	Control	DDGS + midds	Corn oil	Control	DDGS + midds	Corn oil	Control	DDGS + midds	Corn oil	Control	DDGS + midds	Corn oil
DM, %	89.09	90.58	89.41	88.77	90.16	88.93	89.85	90.15	89.81	89.74	91.89	90.61
CP, %	17.1	21	15.3	16.3	20.8	15.9	14.2	22.3	14.0	14.5	18.4	14.3
ADF, %	2.8	7.6	3.0	3.4	5.9	2.8	3.4	8.2	2.8	3.3	6.5	2.6
NDF, %	6.4	16	6.4	5.9	14.4	6.6	6.7	16.8	6.3	5.1	16.5	5.1
Crude fiber, %	1.7	4.2	2.0	1.8	3.5	1.9	2.1	4.8	2.1	1.6	4.3	1.5
Ether extract, %	2.0	4.6	4.2	1.6	4.4	3.8	2.0	3.7	3.2	1.9	4.7	3.5
Ca, %	0.38	0.47	0.61	0.45	0.61	0.55	0.90	0.88	1.19	0.98	0.56	0.56
P, %	0.49	0.66	0.49	0.46	0.66	0.44	0.47	0.58	0.51	0.44	0.64	0.40

[1]A composite sample consisting of 6 subsamples was used for analysis. DDGS = dried distillers grains with solubles; midds = wheat middlings.

[2]Phase 3 diets were fed from d 45 to 70.

[3]Phase 4 diets were fed from d 70 to 87.

Table 11. Analysis of pellet quality, Exp. 2

Item	Diet type		
	Control[1]	DDGS + midds[2]	Corn oil[3]
Standard pellet durability index,[4] %			
Phase 1	93.6	92.0	91.5
Phase 2	94.2	90.4	88.9
Phase 3	94.1	89.9	90.5
Phase 4	90.0	94.3	92.7
Modified pellet durability index[5]			
Phase 1	85.5	84.2	84.8
Phase 2	86.4	84.1	82.5
Phase 3	86.0	84.9	84.0
Phase 4	83.0	87.5	83.0
Fines, %			
Phase 1	10.2	12.4	14.0
Phase 2	11.9	12.7	7.6
Phase 3	7.2	8.8	6.9
Phase 4	7.3	13.6	8.5

[1]Corn–soybean meal–based diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings (midds), and 0% corn oil.

[2]Control diet with 30% DDGS and 19% midds.

[3]Control diet with 3% corn oil.

[4]Pellet durability index was determined using the standard tumbling-box technique.

[5]Procedure was altered by adding 5 hexagonal nuts before tumbling.

creased final BW, but diet form did not influence HCW or carcass yield. Pigs fed diets containing DDGS and midds had decreased ($P < 0.05$) ADG compared with pigs fed the control or corn oil diets. Feeding the corn oil diet resulted in decreased ($P < 0.05$) ADFI compared with feeding the DDGS and midds diet, with pigs fed the control diet intermediate. Feed efficiency followed dietary energy, with pigs fed the corn oil diet having the greatest ($P < 0.05$) G:F, pigs fed the DDGS and midds diet having the poorest ($P < 0.05$) G:F, and pigs fed the control intermediate. Pigs fed the DDGS and midds diet also had the poorest ($P < 0.05$) caloric efficiency on an ME basis; however, when expressed on an NE basis, there were no differences in caloric efficiency between diet types. Pigs fed the diet with DDGS and midds had decreased ($P < 0.05$) HCW and carcass yield compared with pigs fed the control and corn oil treatments.

Belly Fatty Acid Composition. Diet form × diet type interactions were observed ($P < 0.05$) for oleic acid (C18:1n9c), total C18:1, linoleic acid (C18:2n6c), total C18:2, total MUFA, and total PUFA (Table 13). These interactions were a result of a greater magnitude of decrease in C18:1 and increase in C18:2 fatty acids when the control diet was pelleted compared with pelleting the diet containing corn oil, with the diet containing DDGS and midds having an intermediate response to pelleting. An interaction ($P < 0.05$) was also observed for myristic acid (C14:0) in which pelleting the control diet increased C14:0 concentration compared with feeding the diet in meal form, but pelleting either of the other 2 treatment diets decreased C14:0 concentration, with the greatest decrease observed in pigs fed diets containing DDGS and midds.

Feeding pelleted diets also increased ($P < 0.05$) stearic (C18:0) and eicosenoic (C20:1) acids and decreased ($P < 0.05$) vaccenic acid (C18:1n7) compared with feeding meal.

For diet types, pigs fed the control diet had increased ($P < 0.05$) palmitic (C16:0) and reduced ($P < 0.05$) eicosenoic (C20:1) acid concentrations compared with pigs fed the DDGS and midds diet or corn oil diet. Compared with pigs fed the control diet, pigs fed the diet containing DDGS and midds had decreased ($P < 0.05$) stearic acid (C18:0) and total SFA, with those fed the diet containing corn oil intermediate ($P < 0.05$). Pigs fed diets with DDGS and midds had increased ($P < 0.05$) margaric (C17:0) and α-linolenic (C18:3n3) acid concentrations compared with pigs fed either of the other 2 diet types.

No interaction was found between diet form and diet type for belly fat IV. Pigs fed pelleted diets had increased ($P < 0.05$) belly fat IV, and there was no evidence that the increase was influenced by diet type. Belly IV was greatest ($P < 0.05$) for pigs fed diets with DDGS and midds, lowest for pigs fed the control, and intermediate for pigs fed the corn oil diets.

Shoulder Fatty Acid Composition. Similar to those for belly fat, diet form × diet type interactions ($P < 0.05$) occurred for several fatty acids (C16:0, C17:0, C18:1, C18:2, C20:1; Table 14). Pelleting the control diet resulted in a greater increase in UFA and reduction in SFA than pelleting the diet containing corn oil, with the response to pelleting the diet containing wheat midds and DDGS intermediate. These changes in individual fatty acids led to interactions ($P < 0.05$) between diet form and diet type for total MUFA, PUFA, PUFA:SFA ratio, and IV, with tendencies for interactions ($P < 0.10$) for total SFA and UFA:SFA ratio.

For main effects of diet type, pigs fed the control diet had increased ($P < 0.05$) myristic acid compared with pigs fed the diets containing corn oil or DDGS and midds. Feeding corn oil to pigs decreased ($P < 0.05$) vaccenic (C18:1n7) and α-linolenic (C18:3n3) acid concentrations compared with feeding the control diet, and pigs fed the diet containing DDGS and midds were intermediate. Pigs fed corn oil had decreased ($P < 0.05$) stearic acid (C18:0) concentration compared with pigs fed the control diet, with a further decrease ($P < 0.05$) when pigs were fed the diet containing DDGS and midds. For main effects of diet form, pigs fed meal diets had increased ($P < 0.05$) myristic acid (C14:0) concentrations compared with pigs fed pelleted diets.

Table 12. Effects of diet form and type on growth performance and carcass yield, Exp. 2[1]

	Diet form									
	Meal			Pellet				Probability *P*		
Item	Control[2]	DDGS + midds[3]	Corn oil[4]	Control[2]	DDGS + midds[3]	Corn oil[4]	SEM	Diet form × type	Diet form	Diet type
Initial BW, kg	48.5	48.5	48.5	48.5	48.5	48.5	1.041	0.998	0.997	0.996
d 0 to 87										
ADG, kg	0.95	0.91	0.95	0.96	0.94	0.98	0.013	0.706	0.038	0.009
ADFI, kg	2.64	2.66	2.52	2.49	2.63	2.44	0.042	0.372	0.016	0.002
G:F	0.359	0.341	0.378	0.385	0.357	0.401	0.005	0.619	0.001	0.001
Caloric efficiency, Mcal/kg gain										
ME	9.24	9.93	9.19	8.61	9.09	8.64	0.125	0.744	0.001	0.005
NE	7.00	6.94	7.04	6.53	6.62	6.62	0.094	0.699	0.001	0.699
Final BW, kg	130.8	127.3	131.4	131.7	130.1	134.5	1.521	0.747	0.076	0.028
HCW, kg	98.6	93.9	98.6	98.2	95.9	101.6	1.218	0.366	0.132	0.001
Carcass yield, %	75.37	73.82	75.01	74.53	73.75	75.54	0.309	0.163	0.619	0.001

[1]A total of 288 pigs (PIC 327 × 1050, initially 48.5 kg BW) were used in an 87-d trial with 6 pens per treatment and 8 pigs per pen.

[2]Corn–soybean meal–based diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings (midds), and 0% corn oil.

[3]Control diet with 30% DDGS and 19% midds.

[4]Control diet with 3% corn oil.

An interactive effect between diet form and oil source was detected ($P < 0.05$) for shoulder fat IV, which resulted from pigs fed the control or corn oil diet having higher shoulder fat IV when diets were fed as pellets compared with meal form; however, pigs fed the DDGS and midds diet had a slight numeric decrease in shoulder fat IV when fed pelleted diets compared with meal.

DISCUSSION

In Exp. 1, feeding diets containing 30% DDGS and 19% midds did not influence ADG from d 0 to 64, but when pigs were withdrawn from the high-fiber, high-fat diet and switched to a corn–soybean meal–based diet from d 64 to 81, ADG increased compared with that of pigs that remained on the high-fiber, high-fat diet throughout. This response was driven primarily by increases in ADFI. The diets fed in Exp. 1 were similar to those used by Asmus et al. (2014), who investigated the effects of reducing or completely removing DDGS and midds from finishing pig diets for multiple durations. The authors reported similar increases in ADG and ADFI when the high-fiber components were withdrawn from the diet and attributed this effect to the bulk density and energy content of the diets; that is, pigs previously fed high-fiber diets continued to consume higher volumetric amounts of feed despite switching to a more energy-dense diet. Overall, for both experiments, pigs fed the control diets without DDGS or midds had similar ADG and improved G:F compared with those fed 30% DDGS and 19% midds for the entirety of each trial. This is in agreement with the results of Salyer et al. (2012), who reported that pigs fed the combination of DDGS and midds had poorer feed efficiency than those fed diets without cereal grain byproducts. The response to feed efficiency was a result of the energy content in the diets, which was further demonstrated by pigs having similar caloric efficiency on a NE basis in both experiments. The fact that caloric efficiency was influenced by diet type on an ME basis but not on a NE basis illustrates that NE more appropriately describes the energy differences between the diets in these experiments.

Feeding pelleted diets improved growth performance compared with feeding meal diets in both experiments. The overall improvements in ADG were 4% and 3% for Exp. 1 and 2, respectively, whereas the improvements in G:F were approximately 6% for both experiments. These results are in agreement with those of Wondra et al. (1995), who observed a 4% to 6% increase in ADG and 7% improvement in G:F when feeding pelleted diets compared with meal. De Jong et al. (2013a,b) also reported improvements of approximately 6% for ADG and G:F when diets were fed in pellet instead of meal form. However, the beneficial effects of pelleting are not consistent among all research. Myers et al. (2013) found no benefit in G:F when feeding pelleted diets compared with meal. The authors suggested that the lack of response could be partially due to poor pellet quality and a high percentage of fines present in the pelleted diet, leading to increased feed wastage. This is in agreement with the results of Stark et al. (1993) and Nemechek et al. (2012), who reported that feed efficiency of finishing pigs worsened as the percentage of fines in pelleted

Table 13. Effects of diet form and type on belly fatty acid profile, Exp. 2[1]

	Diet form									
	Meal			Pellet				Probability *P*		
Item	Control[2]	DDGS + midds[3]	Corn oil[4]	Control[2]	DDGS + midds[3]	Corn oil[4]	SEM	Diet form × type	Meal vs. pellet	Diet type
Myristic acid (C14:0), %	1.39	1.39	1.36	1.41	1.30	1.33	0.020	0.028	0.034	0.022
Palmitic acid (C16:0), %	23.62	22.16	22.48	23.20	22.27	22.27	0.152	0.239	0.177	0.001
Palmitoleic acid (C16:1), %	3.29	2.95	2.65	2.76	2.46	2.47	0.076	0.056	0.001	0.001
Margaric acid (C17:0), %	0.24	0.27	0.21	0.22	0.27	0.19	0.016	0.545	0.239	0.001
Stearic acid (C18:0), %	10.44	9.07	9.65	10.91	9.24	9.66	0.116	0.148	0.032	0.001
Oleic acid (C18:1n9c), %	46.66	42.56	42.55	44.99	41.66	42.31	0.239	0.019	0.001	0.001
Vaccenic acid (C18:1n7), %	0.93	0.84	0.63	0.73	0.64	0.61	0.048	0.130	0.001	0.001
Total C18:1 fatty acids,[5] %	47.61	43.40	43.11	45.69	42.25	42.88	0.265	0.013	0.001	0.001
Linoleic acid (C18:2n6c), %	11.31	18.30	18.15	13.62	19.64	18.87	0.268	0.020	0.001	0.001
Total C18:2 fatty acids,[6] %	11.94	19.13	18.93	14.31	20.53	19.68	0.274	0.021	0.001	0.001
α-Linolenic acid (C18:3n3), %	0.70	0.72	0.65	0.66	0.69	0.64	0.022	0.765	0.171	0.037
Eicosenoic acid (C20:1), %	0.43	0.71	0.69	0.53	0.77	0.73	0.016	0.181	0.001	0.001
Total SFA,[7] %	35.69	32.89	33.70	35.74	33.07	33.45	0.202	0.545	0.958	0.001
Total MUFA,[8] %	51.33	47.05	46.45	48.99	45.48	46.08	0.318	0.014	0.001	0.001
Total PUFA,[9] %	12.60	19.77	19.49	14.92	21.16	20.23	0.263	0.019	0.001	0.001
UFA:SFA[10]	1.79	2.03	1.96	1.79	2.02	1.98	0.017	0.486	0.885	0.001
PUFA:SFA[11]	0.35	0.60	0.58	0.42	0.64	0.61	0.009	0.096	0.001	0.001
Iodine value,[12] mg/g	66.74	75.40	74.31	68.65	76.45	75.26	0.300	0.229	0.001	0.001

[1]All items calculated as a percentage of the total fatty acid content. Belly fat samples were collected from the ventral side of the belly along the navel edge between the 10th and the 12th ribs.

[2]Corn–soybean meal–based control diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings (midds), and 0% corn oil.

[3]Control diet with 30% DDGS and 19% midds.

[4]Control diet with 3% corn oil.

[5]Total C18:1 fatty acids = [% C18:1n9c] + [% C18:1n7].

[6]Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].

[7]Total SFA = [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].

[8]Total MUFA = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].

[9]Total PUFA = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c,11t] + [% C18:2 10t,12c] + [% C18:2 9c,11c] + [% C18:2 9t,11t] + [% C18:3n6] + [% C18:3n3].

[10]UFA:SFA ratio = [total MUFA + total PUFA]/total SFA.

[11]PUFA:SFA ratio = total PUFA/total SFA.

[12]Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785.

diets increased to above 20%. Our research further supports this concept because growth benefits were observed in the current trials when pigs were fed pelleted diets with high PDI and low percentages of fines.

As in previously reported data (Linneen et al., 2008; Salyer et al., 2012), feeding DDGS and midds before harvest resulted in reduced carcass yield in both experiments. In Exp. 1, however, withdrawing these ingredients 17 d before market improved carcass yield and returned carcass weights to values similar to those of the control-fed pigs. Asmus et al. (2014) also demonstrated that switching pigs from a high-fiber diet to a low-fiber diet 23 d before market allowed for full recovery of carcass yield. In agreement, Coble et al. (2014) reported that removing DDGS and midds 15 to 20 d before harvest allowed carcass yield to return to levels of pigs fed corn–soybean meal–based diets throughout the finishing period. Because the fiber component of the diets caused reduced carcass yield, it was expected that pigs fed the diet containing 3% corn oil in Exp. 2 had carcass yield similar to that of the control-fed pigs. Diet form did not influence carcass yield in either experiment, which agrees with the results of Wondra et al. (1995) and Myers et al. (2013), who reported no differences in carcass yield when finishing pigs were fed diets in meal or pelleted form.

As expected, feeding ingredients high in UFA increased carcass fat IV, which agrees with numerous other publications (Benz et al., 2010, 2011; Cromwell et al., 2011). In Exp. 1, pigs fed the high-fiber, high-fat diet to market had increased concentrations of total C18:2 and PUFA in belly adipose tissue compared with those fed low-fiber, low-fat diets throughout the trial, with those on the withdrawal regimen interme-

Table 14. Effects of diet form and type on shoulder fatty acid profile, Exp. 2[1]

	Diet form									
	Meal			Pellet				Probability *P*		
Item	Control[2]	DDGS + midds[3]	Corn oil[4]	Control[2]	DDGS + midds[3]	Corn oil[4]	SEM	Diet form × type	Meal vs. pellet	Diet type
Myristic acid (C14:0), %	1.35	1.28	1.25	1.29	1.22	1.19	0.021	0.956	0.002	0.001
Palmitic acid (C16:0), %	23.82	22.46	22.54	22.96	23.23	22.64	0.244	0.008	0.974	0.008
Palmitoleic acid (C16:1), %	2.58	2.21	2.04	2.13	1.96	1.84	0.058	0.100	0.001	0.001
Margaric acid (C17:0), %	0.28	0.33	0.27	0.30	0.27	0.24	0.013	0.028	0.064	0.004
Stearic acid (C18:0), %	11.64	10.04	10.45	11.81	10.10	10.49	0.196	0.940	0.579	0.001
Oleic acid (C18:1n9c), %	44.45	40.69	40.74	42.36	39.96	40.20	0.307	0.035	0.001	0.001
Vaccenic acid (C18:1n7), %	0.55	0.51	0.42	0.65	0.47	0.37	0.070	0.469	0.891	0.020
Total C18:1 fatty acids,[5] %	44.87	41.05	40.93	42.76	40.25	40.37	0.301	0.033	0.001	0.001
Linoleic acid (C18:2n6c), %	12.96	19.65	19.71	16.08	20.01	20.38	0.246	0.001	0.001	0.001
Total C18:2 fatty acids,[6] %	13.68	20.55	20.55	16.89	20.96	21.32	0.245	0.001	0.001	0.001
α-Linolenic acid (C18:3n3), %	0.74	0.73	0.69	0.75	0.70	0.67	0.018	0.461	0.366	0.005
Eicosenoic acid (C20:1), %	0.51	0.81	0.81	0.68	0.86	0.85	0.018	0.002	0.001	0.001
Total SFA,[7] %	37.09	34.10	34.51	36.37	34.82	34.56	0.282	0.052	0.946	0.001
Total MUFA,[8] %	47.96	44.07	43.78	45.57	43.07	43.06	0.329	0.038	0.001	0.001
Total PUFA,[9] %	14.55	21.46	21.40	17.73	21.72	22.12	0.244	0.001	0.001	0.001
UFA:SFA[10]	1.69	1.92	1.89	1.74	1.86	1.89	0.023	0.060	0.910	0.001
PUFA:SFA[11]	0.39	0.63	0.62	0.49	0.62	0.64	0.010	0.001	0.001	0.001
Iodine value,[12] mg/g	67.39	75.96	75.53	70.73	75.42	76.14	0.355	0.001	0.001	0.001

[1]All items calculated as a percentage of the total fatty acid content. Fat samples were collected from the shoulder of each pig approximately 5 cm dorsal to the medial ridge of the scapula.

[2]Corn–soybean meal–based control diet with 0% dried distillers grains with solubles (DDGS), 0% wheat middlings (midds), and 0% corn oil.

[3]Control diet with 30% DDGS and 19% midds.

[4]Control diet with 3% corn oil.

[5]Total C18:1 fatty acids = [% C18:1n9c] + [% C18:1n7].

[6]Total C18:2 fatty acids = [% C18:2n6t] + [% C18:2n6c] + [% C18:2, 9c11t] + [% 18:2, 10t12c] + [% C18:2, 9c11c] + [C18:2, 9t11t].

[7]Total SFA = [% C14:0] + [% C15:0] + [% C16:0] + [% C17:0] + [% C18:0] + [% C20:0] + [% C21:0] + [% C22:0] + [% C 24:0].

[8]Total MUFA = [% C14:1] + [% C15:1] + [% C16:1] + [% C17:1] + [% C18:1n9t] + [% C18:1n9c] + [% C18:1n7] + [% C20:1] + [% C24:1].

[9]Total PUFA = [% C18:2n6t] + [% C18:2n6c] + [% C18:2 9c,11t] + [% C18:2 10t,12c] + [% C18:2 9c,11c] + [% C18:2 9t,11t] + [% C18:3n6] + [% C18:3n3].

[10]UFA:SFA ratio = [total MUFA + total PUFA]/total SFA.

[11]PUFA:SFA ratio = total PUFA/total SFA.

[12]Iodine value = [% C16:1] × 0.95 + [% C18:1] × 0.86 + [% C18:2] × 1.732 + [% C18:3] × 2.616 + [% C20:1] × 0.785.

diate. These changes in fatty acid profile, specifically decreases in total PUFA and carcass fat IV, suggest that withdrawing the DDGS and midds from the diet before harvest allowed for improved fat quality compared with feeding these ingredients to market; however, this approach did not return fatty acid concentrations to the same levels as those in pigs fed low-fiber, low-fat regimens throughout the entire study. Withdrawing these ingredients reduced the intake of PUFA provided in the diet; thus, the decrease in belly IV value is most likely related to PUFA intake rather than a direct effect of the fiber on PUFA profile. Similarly, Coble et al. (2014) found that jowl IV decreased linearly with increased withdrawal duration of DDGS and midds, but IV of pigs administered the longest withdrawal treatment of 20 d was still greater than that of pigs fed corn-soybean diets throughout the entire finishing period. Asmus et al. (2014) observed that switching pigs from diets containing DDGS and midds to a corn–soybean meal–based diet 23 d before market reduced jowl fat IV, but further reductions occurred when the withdrawal duration was extended to 47 d before harvest. In Exp. 2, when all diets types were fed for the entire duration of the trial, belly fat IV was increased by 8.2 g/g for pigs fed diets with DDGS and wheat middlings and by 7.1 g/g for pigs fed the corn oil diets compared with pigs fed the control.

Pelleting the diets increased UFA and carcass fat IV in both experiments, but the response to pelleting the different diet types was not consistent. In Exp. 1, the increase in PUFA and IV of belly fat in response to pelleting was greater when DDGS and midds were fed than when the corn–soybean meal diet was fed. The greater belly fat IV from pigs fed pelleted diets was unexpected, particularly because faster-growing pigs will have a lower IV than slower-growing pigs. Lo Fiego et al. (2005) reported that pigs with heaver BW and HCW had decreased PUFA and IV than lighter pigs. The reason for the increase in carcass fat IV is not entirely understood, but 1 hypothesis is that the pelleting process caused increased exogenous fat digestibility and, in turn, resulted in an increase in the amount of dietary oil that is deposited as carcass fat. Chae et al. (1997) reported that pelleting diets increased fat digestibility in finishing pigs. Thus, Exp. 2 was designed to test this hypothesis by including a diet with 3% corn oil. Kim et al. (2013) reported that total tract true digestibility of acid-hydrolyzed ether extract is much greater for extracted corn oil than for the oil contained within DDGS (94.3% vs. 51.9%). Because fat from extracted corn oil is already highly digestible, we expected that pelleting would increase the digestibility of the fat from the DDGS and midds to a greater extent than the fat from corn oil. The results from Exp. 2, however, did not confirm this hypothesis. Pelleting the diets increased belly fat IV, regardless of diet type, and the interactions that occurred for fatty acid profiles of belly and shoulder fat were a result of pelleting increasing the PUFA levels to a greater extent for pigs fed the control diet than those fed the diet containing corn oil or the diet with DDGS and midds. Wondra et al. (1995) observed that feeding pelleted diets increased DM, N, and GE digestibility compared with feeding meal diets. The increase in carcass fat IV from pelleting may be related to the increased digestibility of nonfat nutrients in the diets, allowing fat to be deposited in the fatty acid form in which it is consumed. To our knowledge, the current trials are the first report of fatty acid change due to diet form.

In summary, pigs fed diets with DDGS and midds had poorer growth performance, decreased HCW, reduced carcass yield, and higher carcass fat IV than pigs fed the control diets. In Exp. 1, withdrawing DDGS and midds from the diet 17 d before market fully restored carcass yield to levels similar to the control-fed pigs, but only an intermediate improvement in belly fat IV was observed. The inclusion of ingredients with greater amounts of UFA increased carcass fat IV, regardless of source. Feeding pelleted diets increased ADG and improved G:F, but diet form did not influence HCW or carcass yield in either trial. In both experiments, feeding pelleted diets increased carcass fat IV; furthermore, the source of fat (endogenous from the ingredient vs. supplemental) in pelleted diets does not appear to affect the carcass fat IV response to pelleting.

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