Effects of increasing choice white grease in corn- and sorghum-based diets on growth performance, carcass characteristics, and fat quality characteristics of finishing pigs[1]

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ABSTRACT: A total of 120 pigs (60 barrows and 60 gilts; TR4 × PIC 1050; 54.4 kg initial BW) were used in an 83-d study to evaluate the effects of added fat in corn- and sorghum-based diets on growth performance, carcass characteristics, and carcass fat quality. Treatments were arranged in a 2 × 3 factorial with grain source (corn or sorghum) and added fat (0, 2.5, or 5% choice white grease; CWG) as factors. There were 2 pigs (1 barrow and 1 gilt) per pen and 10 replicate pens per treatment. Pigs and feeders were weighed on d 14, 22, 39, 53, 67, and 83 to calculate ADG, ADFI, and G:F. At the end of the trial, pigs were slaughtered and jowl fat and backfat samples were collected and analyzed for fatty acid profile. No interactions were observed for growth performance. Pigs fed sorghum-based diets had greater ($P < 0.01$) ADG than pigs fed corn-based diets. Adding CWG improved (linear, $P < 0.01$) ADG. Pigs fed corn-based diets tended to have greater ($P < 0.09$) carcass yield, 10th-rib backfat, and percentage lean than pigs fed sorghum-based diets. Adding CWG increased (linear, $P = 0.02$) 10th-rib backfat, tended to increase (linear, $P = 0.08$) HCW, and tended to decrease (linear, $P = 0.07$) percentage lean. There was no grain source × fat level interaction for iodine value (IV) in backfat, but an interaction ($P = 0.03$) was observed for IV in jowl fat. Adding CWG increased ($P < 0.01$) IV in jowl fat for pigs fed sorghum- and corn-based diets; however, the greatest increase was between 0 and 2.5% CWG in sorghum-based diets and between 2.5 and 5% CWG in corn-based diets. Pigs fed corn-based diets had less ($P = 0.01$) C18:1 *cis*-9 and MUFA but greater ($P = 0.01$) C18:2n-6, PUFA, and backfat IV than pigs fed sorghum-based diets. Increasing CWG in the diet increased (linear, $P = 0.01$) backfat IV. Of the 2 fat depots, backfat generally had a reduced IV than jowl fat. In summary, feeding sorghum-based diets reduced carcass fat IV and unsaturated fats compared with corn-based diets. As expected, adding CWG increased carcass fat IV regardless of the cereal grain in the diet.

Key words: added fat, corn, iodine value, pig, sorghum

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INTRODUCTION

The positive effects of added dietary fat on ADG and G:F of growing-finishing pigs are well documented (Pettigrew and Moser, 1991; De la Llata et al., 2001). There is also a strong relationship between dietary fat composition and fatty acid composition of fat depots in pigs (Miller et al., 1990; Shackelford et al., 1990). Fatty acids absorbed from the diet, especially PUFA, specifically inhibit endogenous synthesis of fatty acids (Clarke et al., 1990; Bee et al., 1999, 2002). Therefore, it is possible to manipulate body fat composition by selection of dietary fats (Pettigrew and Esnaola, 2001). Because most common dietary fats are more unsaturated than the triglycerides pigs synthesize, dietary fat can lead to problems with soft carcass fat.

The iodine value (**IV**) of carcass fat provides an overall estimate of fatty acid unsaturation, which can serve as an indirect indicator of carcass fat firmness, flavor, or rancidity (Hugo and Roodt, 2007). Acceptable IV ranges from 70 (Barton-Gade, 1987; Madsen et al., 1992; NPPC, 2000) to 75 g/100 g of fat (Boyd et al., 1997), and some US packing plants have set their maximum IV at 73 g/100 g (D. Petry, Triumph Foods LLC, St.

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Joseph, MO, personal communication). Schinckel et al. (2002) estimated that 80% of the fat deposited by the pig is derived from the cereal source (corn and soybean meal diets with no added fat). Sorghum is a cereal grain that is frequently used in swine diets in regions where it is grown. It has less oil content than corn (NRC, 1998), which may lead to pigs having decreased carcass fat IV. The increasing emphasis on pork fat firmness has increased our need for evidence of the impact of grain source and fat additions on fatty acid profile and IV of pork fat. Our hypothesis was that pigs fed sorghum-based diets could tolerate greater amounts of added dietary fat without negatively affecting fat firmness than those fed corn-based diets. Therefore, the objective of this study was to evaluate the effects of adding dietary fat to corn- and sorghum-based diets on growth performance, carcass characteristics, and carcass fat quality of finishing pigs.

MATERIALS AND METHODS

All experimental procedures used in this study were approved by the Kansas State University Institutional Animal Care and Use Committee.

Animals and Treatments

One hundred twenty crossbred pigs (60 barrows and 60 gilts; TR4 × 1050, PIC, Hendersonville, TN) with an initial BW of 54.4 kg were used in an 83-d experiment. Pigs were blocked by BW and allotted to 1 of 6 treatments. There were 2 pigs per pen, 1 barrow and 1 gilt, and 10 replicate pens per treatment. Pigs were housed in an environmentally regulated finishing barn with 1.52 × 1.52 m pens and totally slatted flooring. Each pen was equipped with a 1-hole dry self-feeder and nipple waterer to allow ad libitum access to feed and water. Treatments were arranged in a 2 × 3 factorial with grain source (corn or sorghum) and added fat (0, 2.5, or 5% choice white grease; **CWG**) as factors. Before the study, all pigs were fed a similar corn-soybean meal-based diet for 7 wk. Diets were fed in 3 phases from d 0 to 22 (Table 1), 22 to 53 (Table 2), and 53 to 83 (Table 3) to correspond with approximate BW ranges of 41 to 68, 68 to 95, and 95 to 123 kg, respectively. A constant standardized ileal digestible Lys:ME (2.58, 2.14, and 1.85 g of Lys/kcal of ME for phases 1, 2, and 3, respectively) was maintained by altering the corn, sorghum, and soybean meal content in the basal diet when adding dietary fat. Dietary IV product (**IVP**) of the diet was calculated using the following equation (Madsen et al., 1992): IVP = (IV of the dietary crude fat) × (percentage dietary crude fat) × 0.10. Pigs and feeders were weighed on d 14, 22, 39, 53, 67, and 83 to calculate ADG, ADFI, and G:F. Treatment differences for the intermediate weight periods were similar to those observed for the d 0 to 83 period; thus, overall data are reported.

Carcass Characteristics and Fat Quality Analysis

Pigs were slaughtered at Triumph Foods LLC (St. Joseph, MO) at the end of the 83-d trial. Pigs were each marked with an individual tattoo before marketing. After exiting the kill floor, carcasses (with head and feet on) were sent through deep chill chambers (approximately −40°C) for approximately 90 min. After deep chill, carcasses were segregated on an outside rail in a holding cooler. Approximately 2 h after exiting deep chill, the right side jowl was removed with a perpendicular cut flush with the carcass shoulder. A small (approximately 100 g) sample of backfat was removed from the 10th-rib area off the carcass midline. An attempt was made to remove all layers of backfat. Jowl fat and backfat samples were placed in a vacuum bag that was vacuum sealed, stored at approximately 4°C, and then transported to Kansas State University under chilled conditions. Carcasses were allowed to chill overnight; then individual carcass data, including HCW, loin and backfat depth, percentage lean, and carcass yield (dressing percentage), were collected. Percentage lean was calculated by the packing plant using a proprietary equation.

Jowl and backfat samples were frozen at −18°C until sample preparation and fatty acid analysis. Samples were thawed and dissected to separate adipose tissue from skin and lean tissue. Adipose tissue was subsampled and ground. Grinding was performed by cutting fat samples into about 1-cm^3 pieces, freezing the pieces in a bath of liquid N_2, and grinding them into very fine particles in a stainless-steel grinding tub powered by a Waring commercial blender (Dynamics Corporation of America, New Hartford, CT). Ground fat (50 μg) was then weighed into screw-cap tubes with Teflon-lined caps. Fat (50 μg) was combined with 2 mL of methanolic-HCl and 3 mL of internal standard [2 mg/mL of methyl heptadecanoic acid (C17:0) in benzene] and subsequently heated in a water bath for 120 min at 70°C for transmethylation. After cooling, addition of 2 mL of benzene and 3 mL of K_2CO_3 allowed the methyl esters to be extracted and transferred to a vial for subsequent quantification of the methylated fatty acids by gas chromatography for fatty acid analysis. From the fatty acid analysis, IV was calculated by using the following equation (AOCS, 1998): IV = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723, where brackets indicate concentration.

Statistical Analysis

Data were analyzed as a randomized complete block design using the MIXED procedure (SAS Inst. Inc., Cary, NC) with the pen as the experimental unit. Pigs were blocked by BW. The statistical model included block as the random effect and grain source and fat lev-

Table 1. Phase 1 diet composition (as-fed basis)[1]

Item	Corn			Sorghum		
	0% added fat	2.5% added fat	5% added fat	0% added fat	2.5% added fat	5% added fat
Ingredient, %						
Corn	72.17	68.18	64.19	—	—	—
Sorghum	—	—	—	72.25	68.22	64.18
Soybean meal (46.5% CP)	25.23	26.70	28.14	25.25	26.73	28.25
Choice white grease	—	2.50	5.00	—	2.50	5.00
Monocalcium phosphate (21% P)	1.03	1.05	1.10	0.93	0.98	1.00
Limestone	0.85	0.85	0.85	0.85	0.85	0.85
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.10	0.10	0.10	0.10	0.10	0.10
Trace mineral premix[3]	0.10	0.10	0.10	0.10	0.10	0.10
L-Lys·HCl	0.15	0.15	0.15	0.15	0.15	0.15
DL-Methionine	0.02	0.02	0.02	0.02	0.02	0.02
Calculated composition						
Total Lys, %	1.07	1.10	1.13	1.04	1.08	1.11
Standardized ileal digestible (SID) AA						
Lys, %	0.95	0.98	1.01	0.93	0.97	1.00
Met:Lys, %	29	29	28	30	29	28
Met+Cys:Lys, %	59	58	56	58	57	56
Thr:Lys, %	61	60	60	64	63	62
Trp:Lys, %	19	19	19	22	22	22
ME, kcal/kg	3,326	3,438	3,548	3,271	3,385	3,500
CP, %	18.0	18.4	18.7	18.5	18.9	19.2
Crude fat, %	3.2	5.6	7.9	2.5	4.9	7.3
Ca, %	0.62	0.63	0.64	0.6	0.61	0.62
Available P, %	0.28	0.29	0.30	0.28	0.29	0.29
SID Lys:ME, g/Mcal	2.58	2.58	2.58	2.58	2.58	2.58
Analyzed value						
Crude fat, %	2.2	5.1	8.4	2.2	4.1	6.7
Dietary fat IV,[4] g/100 g	111.14	92.39	85.71	108.65	87.88	71.32
Dietary IVP[5]	35.56	51.37	72.62	26.88	42.88	51.96

[1]Diet fed in meal form from d 0 to 22.

[2]Provided (per kilogram of diet): 4,410 IU of vitamin A, 551 IU of vitamin D_3, 18 IU of vitamin E, 1.8 mg of vitamin K (as menadione sodium bisulfate), 20 mg of niacin, 3.3 mg of riboflavin, 11 mg of pantothenic acid, and 0.02 mg of B_{12}.

[3]Provided (per kilogram of the diet): 26 mg of Mn (oxide), 110 mg of Fe (sulfate), 110 mg of Zn (oxide), 11 mg of Cu (sulfate), 0.20 mg of I (as Ca iodate), and 0.20 mg of Se (as Na selenite).

[4]Dietary fat iodine value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723, where brackets indicate concentration (AOCS, 1998).

[5]Dietary IV product (IVP) = IV of dietary crude fat × % dietary crude fat × 0.10 (Madsen et al., 1992).

el, and their 2-way interaction, as fixed effects. Hot carcass weight was influenced by treatments so it was used as a covariate for analysis of 10th-rib backfat, last-rib backfat, loin depth, and percentage lean. Least squares means were calculated for each independent variable and evaluated with the PDIFF option of SAS. Contrast statements were used to evaluate linear and quadratic polynomial effects associated with increasing added fat concentrations. Statistical significance and tendencies were set at $P \leq 0.05$ and $P < 0.10$, respectively, for all statistical tests.

RESULTS

Chemical Analysis

The analyzed chemical composition of corn and sorghum used in the study is shown in Table 4. Analyzed values for DM, CP, crude fiber, crude fat content, and essential AA of corn and sorghum were similar to values used in diet formulation.

As expected, analyzed crude fat content was greater for the corn-based diets than the sorghum-based diets and increased in a linear manner as fat was added to the diets (Tables 1, 2, and 3). Analyzed dietary fat IV of diets with 0, 2.5, and 5.0% added fat was 115.1, 95.5, and 84.8 g/100 g, respectively, for the corn-based diets and 103.4, 88.0, and 79.4 g/100 g, respectively, for the sorghum-based diets. Dietary IVP averaged 38.8, 54.7, and 70.3 for the corn-based diets and 24.5, 43.8, and 58.7 for the sorghum-based diets with 0, 2.5, and 5.0% added fat, respectively.

Growth Performance

Overall, there was no interaction observed for any of the growth criteria measured (Table 5). Pigs fed sorghum-based diets had greater ($P < 0.01$) ADG than

Table 2. Phase 2 diet composition (as-fed basis)[1]

Item	Corn			Sorghum		
	0% added fat	2.5% added fat	5% added fat	0% added fat	2.5% added fat	5% added fat
Ingredient, %						
Corn	80.25	76.53	72.81	—	—	—
Sorghum	—	—	—	80.09	76.37	72.58
Soybean meal (46.5% CP)	17.27	18.47	19.66	17.53	18.73	19.97
Choice white grease	—	2.50	5.00	—	2.50	5.00
Monocalcium phosphate (21% P)	0.93	0.95	0.98	0.83	0.85	0.90
Limestone	0.85	0.85	0.85	0.85	0.85	0.85
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.10	0.10	0.10	0.10	0.10	0.10
Trace mineral premix[3]	0.10	0.10	0.10	0.10	0.10	0.10
L-Lys·HCl	0.15	0.15	0.15	0.15	0.15	0.15
Calculated composition						
Total Lys, %	0.85	0.87	0.90	0.82	0.85	0.88
Standardized ileal digestible (SID) AA						
Lys, %	0.75	0.78	0.80	0.74	0.76	0.79
Met:Lys ratio,%	30	30	29	31	30	29
Met+Cys:Lys ratio, %	63	61	60	62	60	59
Thr:Lys, %	63	62	61	67	66	65
Trp:Lys, %	19	19	19	23	23	22
ME, kcal/kg	3,333	3,445	3,555	3,271	3,385	3,500
CP, %	15.0	15.2	15.5	15.7	15.9	16.1
Crude fat, %	3.4	5.8	8.1	2.6	5.0	7.4
Ca, %	0.58	0.58	0.59	0.56	0.57	0.58
Available P, %	0.25	0.26	0.26	0.25	0.25	0.26
SID Lys:ME, g/Mcal	2.14	2.14	2.14	2.14	2.14	2.14
Analyzed value						
Crude fat, %	3.3	5.9	8.6	2.2	4.8	6.1
Dietary fat IV,[4] g/100 g	113.97	94.99	84.76	106.83	90.83	83.71
Dietary IVP[5]	38.75	54.73	68.95	21.76	45.38	61.98

[1]Diet fed in meal form from d 22 to 53.

[2]Provided (per kilogram of diet): 4,410 IU of vitamin A, 551 IU of vitamin D_3, 18 IU of vitamin E, 1.8 mg of vitamin K (as menadione sodium bisulfate), 20 mg of niacin, 3.3 mg of riboflavin, 11 mg of pantothenic acid, and 0.02 mg of B_{12}.

[3]Provided (per kilogram of the diet): 26 mg of Mn (oxide), 110 mg of Fe (sulfate), 110 mg of Zn (oxide), 11 mg of Cu (sulfate), 0.20 mg of I (as Ca iodate), and 0.20 mg of Se (as Na selenite).

[4]Dietary fat iodine value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723, where brackets indicate concentration (AOCS, 1998).

[5]Dietary IV product (IVP) = IV of dietary crude fat × % dietary crude fat × 0.10 (Madsen et al., 1992).

pigs fed corn-based diets. The difference in ADG was due to a numerical ($P = 0.15$) increase in ADFI for pigs fed sorghum-based diets, as there was no difference in G:F. Increasing CWG improved (linear, $P < 0.01$) ADG; however, there were no differences in ADFI or G:F.

Carcass Characteristics

A tendency ($P = 0.06$) for a grain source × fat level interaction for 10th-rib fat depth was observed (Table 5). In pigs fed corn-based diets, the greatest increase in 10th-rib backfat was observed as CWG increased from 0 and 2.5%; however, for pigs fed sorghum-based diets, the greatest increase was observed as CWG increased from 2.5 to 5%. Pigs fed corn-based diets tended to have greater ($P = 0.09$) carcass yield and percentage lean and thinner ($P = 0.06$) 10th-rib backfat than pigs fed sorghum-based diets. No differences in HCW, loin depth, or last-rib backfat were observed between corn- and sorghum-based diets. Increasing CWG tended to increase HCW (linear, $P = 0.08$), 10th-rib backfat (linear, $P = 0.02$), and loin depth (quadratic, $P = 0.03$), and tended to decrease (linear, $P = 0.07$) percentage lean.

Carcass Fat Quality

There was no grain source × fat level interaction for backfat quality (Table 6). Backfat of pigs fed corn-based diets had less ($P = 0.01$) C18:1 *cis*-9, C18:1n-7, and MUFA but greater ($P = 0.01$) C18:2n-6, other, and PUFA:SFA than that of pigs fed sorghum-based diets. No differences in C16:0, C18:0, C18:3n-3, SFA, total *trans* fatty acids, or unsaturated fatty acid (**UFA**):SFA were observed in backfat of pigs fed corn- and sorghum-based diets. Increasing CWG linearly increased ($P = 0.01$) C18:1 *cis*-9 in backfat. Likewise, C18:2n-6, C18:3n-3, other PUFA, MUFA, UFA:SFA, and PUFA:SFA increased (quadratic, $P < 0.03$) in backfat, with most of the increase occurring as added dietary CWG increased from 0 to 2.5%. In contrast, increasing dietary CWG

Table 3. Phase 3 diet composition (as-fed basis)[1]

Item	Corn			Sorghum		
	0% added fat	2.5% added fat	5% added fat	0% added fat	2.5% added fat	5% added fat
Ingredient, %						
Corn	84.18	80.54	76.97	—	—	—
Sorghum	—	—	—	83.90	80.35	76.74
Soybean meal (46.5% CP)	13.44	14.56	15.60	13.82	14.82	15.91
Choice white grease	—	2.50	5.00	—	2.50	5.00
Monocalcium phosphate (21% P)	0.88	0.90	0.93	0.78	0.83	0.85
Limestone	0.80	0.80	0.80	0.80	0.80	0.80
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.10	0.10	0.10	0.10	0.10	0.10
Trace mineral premix[3]	0.10	0.10	0.10	0.10	0.10	0.10
L-Lys·HCl	0.15	0.15	0.15	0.15	0.15	0.15
Calculated composition						
Total Lys, %	0.74	0.77	0.79	0.72	0.74	0.77
Standardized ileal digestible (SID) AA						
Lys, %	0.65	0.68	0.70	0.64	0.66	0.69
Met:Lys ratio, %	32	31	30	33	32	31
Met+Cys:Lys, %	66	65	63	65	63	62
Thr:Lys, %	64	63	62	69	67	66
Trp:Lys, %	19	19	19	23	23	23
ME, kcal/kg	3,337	3,449	3,562	3,273	3,388	3,502
CP, %	13.5	13.8	13.9	14.3	14.4	14.6
Crude fat, %	3.5	5.9	8.2	2.6	5.1	7.5
Ca, %	0.54	0.54	0.55	0.52	0.53	0.54
Available P, %	0.24	0.24	0.25	0.23	0.24	0.25
SID Lys:ME, g/Mcal	1.85	1.85	1.85	1.85	1.85	1.85
Analyzed value						
Crude fat, %	3.1	5.6	8.6	2.2	3.5	6.7
Dietary fat IV,[4] g/100 g	120.30	99.03	84.03	94.62	85.38	83.21
Dietary IVP[5]	42.11	58.03	69.21	24.99	43.14	62.11

[1]Diet fed in meal form from d 53 to 83.

[2]Provided (per kilogram of diet): 4,410 IU of vitamin A, 551 IU of vitamin D_3, 18 IU of vitamin E, 1.8 mg of vitamin K (as menadione sodium bisulfate), 20 mg of niacin, 3.3 mg of riboflavin, 11 mg of pantothenic acid, and 0.02 mg of B_{12}.

[3]Provided (per kilogram of the diet): 26 mg of Mn (oxide), 110 mg of Fe (sulfate), 110 mg of Zn (oxide), 11 mg of Cu (sulfate), 0.20 mg of I (as Ca iodate), and 0.20 mg of Se (as Na selenite).

[4]Dietary fat iodine value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723, where brackets indicate concentration (AOCS, 1998).

[5]Dietary IV product (IVP) = IV of dietary crude fat × % dietary crude fat × 0.10 (Madsen et al., 1992).

Table 4. Analyzed chemical composition of dietary ingredients and values used in diet formulation (as-fed basis)

Item	Corn		Sorghum	
	Assumed[1]	Analyzed[2]	Assumed[1]	Analyzed[2]
Proximate analysis, %				
DM	89.0	89.2	89.0	89.1
CP (N × 6.25)	8.5	8.1	9.2	9.0
Crude fiber	2.2	2.2	2.4	2.2
Ether extract	3.5	3.7	2.9	3.2
Essential AA, %				
Lys	0.26	0.24	0.22	0.23
Ile	0.28	0.25	0.37	0.33
Leu	0.99	0.84	1.21	1.19
Met	0.17	0.15	0.17	0.16
Cys	0.19	0.17	0.17	0.15
Thr	0.29	0.28	0.31	0.30
Trp	0.06	0.05	0.10	0.08
Val	0.39	0.34	0.46	0.42

[1]Represents assumed values used in diet formulation.

[2]Values represent the mean of 1 sample.

Table 5. Interactive effects of adding fat to corn- and sorghum-based diets on growth performance and carcass characteristics of finishing pigs[1]

	Corn			Sorghum					*P*-value			
										Fat level		
Item	0% added fat	2.5% added fat	5% added fat	0% added fat	2.5% added fat	5% added fat	Fat level SE	Source SE	Source	Linear	Quadratic	Source × fat level
Growth performance (d 0 to 83)												
ADG, kg	0.89	0.93	0.97	0.95	0.99	1.01	0.02	0.01	0.01	0.01	0.98	0.89
ADFI, kg	2.55	2.61	2.53	2.67	2.64	2.73	0.01	0.01	0.15	0.51	0.23	0.61
G:F	0.35	0.35	0.38	0.36	0.37	0.37	0.01	0.01	0.90	0.18	0.16	0.68
Carcass characteristic												
HCW, kg	93.9	97.1	98.7	96.5	100.2	100.4	1.2	1.0	0.46	0.08	0.92	0.34
Yield, %	73.0	73.6	73.3	72.2	72.8	72.4	0.37	0.30	0.06	0.28	0.36	0.91
10th-rib fat,[2] mm	16.5	18.3	18.0	18.3	18.3	20.6	1.5	1.3	0.06	0.02	0.77	0.06
Loin depth,[2] mm	61.0	63.5	63.0	61.2	64.8	62.2	23.6	18.8	0.98	0.52	0.03	0.80
Last-rib fat,[2] mm	22.4	25.1	24.9	24.1	24.4	25.4	1.5	0.8	0.83	0.18	0.61	0.44
Lean,[2] %	53.9	53.6	53.4	53.2	53.5	52.3	0.28	0.26	0.09	0.07	0.13	0.13

[1]Total of 120 pigs (60 barrows and 60 gilts, TR4 × PIC 1050; initial BW of 54.4 kg) with 2 pigs per pen and 10 replicates per treatment. Fat added was choice white grease.
[2]HCW used as a covariate for statistical analysis.

resulted in a decrease ($P < 0.03$) in C14:0, C16:0, and SFA and tended to decrease ($P < 0.08$) C18:0 in backfat. Increasing added CWG did not affect total *trans* fatty acid concentration in backfat. Pigs fed corn-based diets had greater ($P < 0.01$) backfat IV than pigs fed sorghum-based diets. Increasing CWG in the diet increased (linear, $P < 0.01$) backfat IV.

There was a grain source × fat level interaction ($P < 0.05$) for C18:1 *cis*-9, PUFA, PUFA:SFA, and IV in jowl fat (Table 7). For C18:1 *cis*-9, the interaction was due to a greater increase in jowl fat of pigs fed corn-based diets (1.6 percentage units) than in sorghum-based diets (1.18 percentage units) when added CWG increased from 0 to 5%. Concentrations of PUFA, PUFA:SFA, and IV increased in corn-based diets when added CWG levels increased from 2.5 to 5%; however, the increase was observed when added CWG increased from 0 to 2.5% in sorghum-based diets. Other interactions ($P < 0.05$) were observed for C14:0, C18:3 *cis*-3, and C20:2. The interaction for C14:0 was a result of added fat increasing C14:0, then it returning to control values in corn-based diets, but decreasing with added fat in sorghum-based diets. The interaction for C18:3n-3 was similar to that observed for IV. Jowl fat of pigs fed corn-based diets had greater ($P = 0.01$) C18:2n-6 and less ($P = 0.01$) MUFA than that of pigs fed sorghum-based diets (Table 7). No differences in SFA, total *trans* fatty acids, or UFA:SFA were observed between pigs fed corn- and sorghum-based diets. Increasing dietary added fat reduced ($P < 0.02$) concentrations of C18:0 and SFA in jowl fat. In contrast, MUFA and UFA:SFA were increased ($P = 0.01$) and total *trans* fatty acids tended to increase ($P < 0.07$) in jowl fat as added dietary fat increased from 0 to 5%.

DISCUSSION

Conventionally, grain sorghum is ascribed a reduced feeding value compared with corn because of its reduced energy value, greater variability in nutrient content, and feed processing issues. In a summary involving 10 growing-finishing experiments, Cromwell et al. (1985) showed that pigs fed sorghum had 98% of the ADG and 97% of the G:F of pigs fed corn. However, more recent studies, including the current study, reveal a greater feeding value for sorghum in finishing pigs (Johnston et al., 1998; Shelton et al., 2004; Issa, 2009). On average, pigs fed sorghum-based diets in these studies had 103 and 98% of the ADG and G:F, respectively, of finishing pigs fed corn. The improvement in ADG observed in sorghum-fed pigs in the current study was due to a 5% numeric increase in ADFI, which is consistent with recent studies (Johnston et al., 1998; Shelton et al., 2004; Issa, 2009) where feeding sorghum increased ADFI by 6% (range: 0 to 14%) compared with feeding corn-based diets. The improvements compared with earlier studies in the relative value of feeding sorghum may be mainly due to the introduction and widespread use of low-tannin varieties of sorghum and better knowledge

Table 6. Effects of adding fat to corn- and sorghum-based diets on backfat quality of finishing pigs[1]

Item	Corn			Sorghum					P-value			
										Fat level		
	0% added fat	2.5% added fat	5% added fat	0% added fat	2.5% added fat	5% added fat	Fat level SE	Source SE	Source	Linear	Quadratic	Source × fat level
Myristic acid (C14:0), %	1.45	1.41	1.36	1.50	1.40	1.40	0.02	0.02	0.27	0.01	0.41	0.55
Palmitic acid (C16:0), %	25.15	24.04	23.43	25.52	23.70	24.08	0.22	0.18	0.26	0.01	0.02	0.23
Palmitoleic acid (C16:1), %	2.43	2.29	2.25	2.55	2.38	2.41	0.07	0.06	0.10	0.14	0.41	0.95
Margaric acid (C17:0), %	0.59	0.61	0.59	0.56	0.63	0.59	0.01	0.01	0.69	0.52	0.05	0.34
Stearic acid (C18:0), %	13.32	12.34	11.89	13.42	11.89	12.12	0.25	0.20	0.97	0.01	0.08	0.54
Oleic acid (C18:1 *cis*-9), %	37.67	38.66	39.93	39.70	40.58	40.94	0.04	0.04	0.01	0.01	0.45	0.19
Vaccenic acid (C18:1n-7), %	2.67	2.76	2.91	2.91	3.10	3.03	0.33	0.27	0.01	0.01	0.96	0.53
Linoleic acid (C18:2n-6), %	13.76	14.78	14.47	11.03	13.24	12.45	0.31	0.25	0.01	0.02	0.01	0.37
α-Linolenic acid (C18:3n-3), %	0.65	0.72	0.71	0.66	0.76	0.70	0.02	0.01	0.53	0.03	0.01	0.65
Arachidic acid (C20:0), %	0.26	0.25	0.23	0.25	0.22	0.24	0.01	0.01	0.09	0.01	0.09	0.14
Eicosadienoic acid (C20:2), %	0.66	0.74	0.77	0.56	0.70	0.65	0.02	0.01	0.01	0.01	0.01	0.22
Arachidonic acid (C20:4n-6), %	0.21	0.22	0.23	0.19	0.22	0.22	0.01	0.01	0.07	0.01	0.26	0.43
Other fatty acids, %	1.16	1.18	1.21	1.16	1.19	1.18	0.03	0.02	0.77	0.36	0.77	0.79
Total SFA,[2] %	41.27	39.15	38.00	41.77	38.34	38.92	0.41	0.34	0.54	0.01	0.03	0.26
Total MUFA,[3] %	43.11	44.02	45.46	45.50	46.40	46.72	0.39	0.32	0.01	0.01	0.01	0.50
Total PUFA,[4] %	15.62	16.82	16.54	12.73	15.26	14.36	0.34	0.28	0.01	0.02	0.01	0.37
Total *trans* fatty acids,[5] %	0.28	0.26	0.30	0.28	0.29	0.31	0.01	0.01	0.58	0.16	0.36	0.68
UFA:SFA[6]	1.43	1.56	1.63	1.40	1.62	1.58	0.03	0.02	0.62	0.01	0.03	0.24
PUFA:SFA[7]	0.38	0.43	0.44	0.31	0.40	0.37	0.01	0.01	0.01	0.01	0.01	0.33
IV,[8] g/100 g	63.77	66.55	67.21	60.96	65.95	64.68	0.55	0.45	0.01	0.01	0.01	0.27

[1]Total of 120 pigs (60 barrows and 60 gilts, TR4 × PIC 1050; initial BW of 54.4 kg) with 2 pigs per pen and 10 replicates per treatment. Fat added was choice white grease.

[2]Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]), where brackets indicate concentration.

[3]Total MUFA = ([C14:1] + [C16:1] + [C18:1 *cis*-9] + [C18:1n-7] + [C20:1] + [C24:1]), where brackets indicate concentration.

[4]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]), where brackets indicate concentration.

[5]Total *trans* (*t*) fatty acids = ([C18:1*t*] + [C18:2*t*] + [C18:3*t*]), where brackets indicate concentration.

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

[7]PUFA:SFA = total PUFA/total SFA.

[8]Calculated as iodine value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723, where brackets indicate concentration (AOCS, 1998).

Table 7. Effects of adding fat to corn- and sorghum-based diets on jowl fat quality of finishing pigs[1]

	Corn			Sorghum					*P*-value			
										Fat level		
Item	0% added fat	2.5% added fat	5% added fat	0% added fat	2.5% added fat	5% added fat	Fat level SE	Source SE	Source	Linear	Quadratic	Source × fat level
Myristic acid (C14:0), %	1.45	1.52	1.42	1.56	1.45	1.44	0.03	0.02	0.41	0.09	0.52	0.05
Palmitic acid (C16:0), %	23.29	23.10	22.04	24.00	22.71	22.57	0.21	0.17	0.16	0.01	0.84	0.08
Palmitoleic acid (C16:1), %	3.08	3.00	3.03	3.29	2.98	2.83	0.07	0.06	0.93	0.03	0.42	0.09
Margaric acid (C17:0), %	0.55	0.52	0.56	0.50	0.55	0.52	0.01	0.01	0.32	0.64	0.68	0.14
Stearic acid (C18:0), %	10.18	9.72	8.82	10.22	9.62	9.63	0.18	0.14	0.19	0.01	0.90	0.22
Oleic acid (C18:1 *cis*-9), %	40.26	41.39	41.86	42.07	42.34	43.25	0.26	0.21	0.01	0.09	0.49	0.02
Vaccenic acid (C18:1n-7), %	3.33	3.45	3.49	3.42	3.22	3.50	0.13	0.11	0.81	0.61	0.47	0.62
Linoleic acid (C18:2n-6), %	14.53	14.09	15.30	11.93	13.81	12.99	0.32	0.26	0.01	0.01	0.94	0.68
α-Linolenic acid (C18:3n-3), %	0.87	0.83	0.90	0.81	0.91	0.83	0.02	0.02	0.37	0.58	0.63	0.04
Arachidic acid (C20:0), %	0.20	0.20	0.18	0.20	0.18	0.20	0.01	0.003	0.94	0.24	0.87	0.06
Eicosadienoic acid (C20:2), %	0.73	0.74	0.82	0.62	0.74	0.75	0.02	0.01	0.01	0.01	0.68	0.04
Arachidonic acid (C20:4n-6), %	0.28	0.26	0.29	0.23	0.27	0.25	0.01	0.01	0.03	0.38	0.91	0.07
Other fatty acids, %	1.24	1.17	1.29	1.14	1.23	1.23	0.03	0.03	0.48	0.28	0.51	0.17
Total SFA,[2] %	36.21	35.56	33.49	36.98	35.02	34.87	0.37	0.29	0.14	0.01	0.89	0.14
Total MUFA,[3] %	47.04	48.18	48.81	49.11	48.90	49.97	0.32	0.26	0.01	0.02	0.54	0.44
Total PUFA,[4] %	16.76	16.27	17.70	13.91	16.09	15.16	0.37	0.30	0.01	0.08	0.51	0.02
Total *trans* fatty acids,[5] %	0.28	0.27	0.38	0.30	0.31	0.32	0.02	0.02	0.77	0.07	0.12	0.22
UFA:SFA[6]	1.77	1.81	1.99	1.71	1.86	1.87	0.03	0.02	0.13	0.01	0.98	0.12
PUFA:SFA[7]	0.47	0.46	0.53	0.38	0.46	0.44	0.01	0.01	0.01	0.02	0.72	0.03
IV,[8] g/100 g	69.24	69.30	72.24	66.22	69.64	68.87	0.57	0.46	0.01	0.01	0.66	0.03

[1]Total of 120 pigs (60 barrows and 60 gilts, TR4 × PIC 1050; initial BW of 54.4 kg) with 2 pigs per pen and 10 replicates per treatment. Fat added was choice white grease.

[2]Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]), where brackets indicate concentration.

[3]Total MUFA = ([C14:1] + [C16:1] + [C18:1 *cis*-9] + [C18:1 n-7] + [C20:1] + [C24:1]), where brackets indicate concentration.

[4]Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]), where brackets indicate concentration.

[5]Total *trans* (*t*) fatty acids = ([C18:1*t*] + [C18:2*t*] + [C18:3*t*]), where brackets indicate concentration.

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

[7]PUFA:SFA = total PUFA/total SFA.

[8]Calculated as iodine value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723, where brackets indicate concentration (AOCS, 1998).

about processing sorghum-based diets. Considered together, all these research results indicate grain sorghum can replace corn in finishing pig diets without affecting growth performance.

Feeding sorghum to finishing pigs did not affect HCW, loin depth, or last-rib backfat; however, sorghum-fed pigs tended to have less carcass yield and percentage lean and thicker 10th-rib backfat than pigs fed corn-based diets. This is in contrast with previous studies (Hancock et al., 1992; Johnston et al., 1998; Shelton et al., 2004), which showed no differences in carcass yield between pigs fed corn- or sorghum-based diets. Shelton et al. (2004) also did not observe differences in percentage lean. The decreased carcass yield and leanness of pigs fed sorghum observed in the present study may be due to greater energy intake compared with pigs fed corn, which may have resulted in increased carcass fatness.

Adding CWG increased dietary energy and, consistent with previous studies (Campbell and Taverner, 1988; Southern et al., 1989; De la Llata et al., 2001), resulted in linear improvements in ADG. Feeding increasing CWG to pigs tended to increase HCW, increased 10th-rib backfat, increased loin depth, and tended to decrease percentage lean. De la Llata et al. (2001) also found an increase in backfat depth when 6% CWG was added to diets for the entire experiment. Energy consumed in excess of that needed to maximize lean deposition goes to fat accretion and further increases in energy intake reduce carcass leanness (Pettigrew and Esnaola, 2001). This indicates that the concentration of CWG added to both the corn- and sorghum-based diets provided additional energy over that needed for maximal lean deposition. The excess energy also may have limited the response in feed efficiency to a numerical and nonsignificant response.

Technological aspects of meat quality such as fat tissue firmness, shelf life (lipid and pigment oxidation), and flavor are largely influenced by fat content and fatty acid profile of the carcass (Wood et al., 2003). Soft carcass fat is a major quality issue in pork processing because it leads to difficulty in fabricating and slicing bellies for bacon, an oily appearance in retail packaging, a reduced product shelf life, and an increased susceptibility to oxidative damage (Wood and Enser, 1997; NPPC, 2000; Xu et al., 2010). Linoleic acid (C18:2n-6) has been shown to have the greatest impact on fat firmness of all fatty acids (Berschauer, 1984). Boyd et al. (1997) and Averette Gatlin et al. (2003) showed that increasing the amount of unsaturated dietary fats increases linoleic acid content in backfat. In the present study, feeding corn-based diets to pigs resulted in greater concentrations of C18:2n-6 and other PUFA in backfat than feeding sorghum, which is reflective of the greater fat content and C18:2n-6 concentration of corn. About 40 to 70% of the fatty acids in corn oil are C18:2n-6 (White et al., 2007), which is greater than the typical concentration of this fatty acid (28 to 51%) in sorghum oil (Mehmood et al., 2008). Numerous researchers suggested that C18:2n-6 should be less than 15% to be considered good quality fat (Wood, 1983; Whittington et al., 1986; Lizardo et al., 2002). In the present study, feeding corn or sorghum as the grain source even with added CWG as much as 5% of the diet resulted in acceptable fat, though feeding corn produced backfat with a C18:2n-6 concentration closer to the maximum limit.

Measures such as fat IV, PUFA:SFA, and belly firmness have been established to determine acceptable levels of fat quality. Pigs fed sorghum-based diets had an IV in backfat and jowl fat approximately 2 g/100 g less than that in pigs fed corn-based diets. The increase in jowl fat and backfat IV from increasing dietary CWG agrees with findings of Weber et al. (2006), who observed an increase in IV in backfat and belly fat from feeding pigs soybean oil, CWG, or beef tallow. This increase was due to an increase in the percentage of PUFA in the diet. Dietary polyunsaturated fats are the most effective inhibitors of de novo fatty acid synthesis (Clarke et al., 1990; Bee et al., 1999, 2002). Therefore, increasing the amounts of these fats in diets causes pigs to deposit more unsaturated dietary fats, which increases carcass IV.

It is important to determine the congruence of jowl fat with other fat depots, such as backfat. Backfat IV was generally less than jowl fat IV; however, increasing CWG in both corn- and sorghum-based diets narrowed the difference. Benz et al. (2007a) observed similar results; in their study, as feeding duration of CWG increased, backfat IV became more similar to jowl fat IV. In the current study, the rate of change for jowl fat IV with increasing CWG was smaller than that for backfat. This may indicate that jowl fat is less responsive than backfat to changes in dietary fatty acid composition.

Madsen et al. (1992) and Boyd et al. (1997) developed equations to predict backfat IV by calculating IVP. Iodine value product is calculated as (IV of the dietary crude fat) × (percentage dietary crude fat) × 0.10. Boyd et al. (1997) estimated backfat IV as 52.4 × 0.315 (diet IVP). These equations provide a means of estimating maximum limits for alternative feeds high in fat or different dietary fat sources in the diet to meet IV standards. Pigs fed corn- or sorghum-based diets with no added fat had a backfat IV similar to what was predicted by the equation; however, adding CWG resulted in analyzed backfat IV values that were less than predicted values. Benz et al. (2007a) observed similar results (i.e., predicted IV of pigs fed greater quantity of CWG were greater than analyzed values). These data indicate the prediction equation did not accurately predict actual backfat IV when pigs were fed diets with various levels of unsaturated fats. More studies are needed to validate or improve the accuracy of using IVP to predict carcass fat IV.

In conclusion, feeding CWG to finishing pigs increased the softness of fat depots as measured by IV and the amount of linoleic acid. Substituting sorghum for corn reduced IV and the percentage of linoleic acid to the point that pigs fed sorghum-based diets with 5% CWG and pigs fed corn-based diets with no added fat had similar IV and percentages of linoleic acid. Therefore, producers can feed greater energy sorghum-based diets, while having fewer concerns about fat quality. Additionally, if pigs fed corn-based diets are at or just above the maximum IV, corn could be substituted by sorghum to prevent exceeding this threshold.

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