Effects of dietary wheat middlings, distillers dried grains with solubles, and choice white grease on growth performance, carcass characteristics, and carcass fat quality of finishing pigs[1]

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ABSTRACT: Two experiments were conducted to evaluate the effects of adding combinations of wheat middlings (midds), distillers dried grains with solubles (DDGS), and choice white grease (CWG) to growing-finishing pig diets on growth, carcass traits, and carcass fat quality. In Exp. 1, 288 pigs (average initial BW = 46.6 kg) were used in an 84-d experiment with pens of pigs randomly allotted to 1 of 4 treatments with 8 pigs per pen and 9 pens per treatment. Treatments included a corn-soybean meal-based control, the control with 30% DDGS, the DDGS diet with 10% midds, or the DDGS diet with 20% midds. Diets were fed in 4 phases and formulated to constant standardized ileal digestible (SID) Lys:ME ratios within each phase. Overall (d 0 to 84), pigs fed diets containing increasing midds had decreased (linear, $P \leq 0.02$) ADG and G:F, but ADFI was not affected. Feeding 30% DDGS did not influence growth. For carcass traits, increasing midds decreased (linear, $P < 0.01$) carcass yield and HCW but also decreased (quadratic, $P = 0.02$) backfat depth and increased (quadratic, $P < 0.01$) fat-free lean index (FFLI). Feeding 30% DDGS decreased ($P = 0.03$) carcass yield and backfat depth ($P < 0.01$) but increased FFLI ($P = 0.02$) and jowl fat iodine value ($P < 0.01$). In Exp. 2, 288 pigs (initial BW = 42.3 kg) were used in an 87-d experiment with pens of pigs randomly allotted to 1 of 6 dietary treatments with 8 pigs per pen and 6 pens per treatment. Treatments were arranged in a 2 × 3 factorial with 2 amounts of midds (0 or 20%) and 3 amounts of CWG (0, 2.5, or 5.0%). All diets contained 15% DDGS. Diets were fed in 4 phases and formulated to constant SID Lys:ME ratios in each phase. No CWG × midds interactions were observed. Overall (d 0 to 87), feeding 20% midds decreased ($P < 0.01$) ADG and G:F. Pigs increasing CWG had improved ADG (quadratic, $P = 0.03$) and G:F (linear, $P < 0.01$). Dietary midds or CWG did not affect ADFI. For carcass traits, feeding 20% midds decreased ($P < 0.05$) carcass yield, HCW, backfat depth, and loin depth but increased ($P < 0.01$) jowl fat iodine value. Pigs fed CWG had decreased (linear, $P < 0.05$) FFLI and increased (linear, $P < 0.01$) jowl fat iodine value. In conclusion, feeding midds reduced pig growth performance, carcass yield, and increased jowl fat iodine value. Although increasing diet energy with CWG can help mitigate negative effects on live performance, CWG did not eliminate negative impacts of midds on carcass yield, HCW, and jowl fat iodine value.

Key words: carcass yield, distillers dried grains with solubles, finishing pig, growth, wheat middlings

J. Anim. Sci. 2012.90:2620–2630
doi:10.2527/jas2011-4472

INTRODUCTION

Feed costs represent 60 to 75% of the total cost of pork production. With increased use of corn in ethanol production, ingredient costs have increased; thus, other ingredients, in addition to corn and soybean meal, are

[1]Appreciation is expressed to D. Donovan, J. Lehenbauer, and Triumph Foods Inc. (St. Joseph, MO) for assistance in carcass data and sample collection.

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Received July 13, 2011.
Accepted February 2, 2012.

used more frequently in swine diets. Although these ingredients are used with the intent of lowering feed costs, knowing their impact on growth and carcass traits is important.

Wheat middlings (**midds**) are a common cereal by-product used in commercial pig diets (Cromwell, 2000). The addition of midds to finishing diets supplies energy, CP, P, and fiber. Wheat middlings contain more CP and fiber than corn (NRC, 1998). Distillers dried grains with solubles (**DDGS**) is a co-product from the ethanol industry that contains approximately 3 times more crude fat, CP, and fiber than corn. Also, DDGS has a greater P bioavailability than corn (Pedersen et al., 2007). Stein and Shurson (2009) reported no negative impact on growth performance when up to 30% DDGS was added to finishing pig diets. In addition, DDGS has DE and ME concentrations similar to corn (Pedersen et al., 2007), whereas midds have a reduced ME concentration compared with corn; thus, reduced gains and feed efficiency might be expected when midds is added to corn-soybean meal diets (Shaw et al., 2002).

Including a dietary energy source such as choice white grease (**CWG**) when midds are used may mitigate these negative effects, but information on the effect of this combination on growth performance is limited and information on the impact on carcass fat iodine value does not exist. Also, no data have been published on the impact of midds in diets containing DDGS. Our objective was to determine effects of dietary midds, DDGS, and CWG in combinations in corn-soybean meal-based diets on growth performance, carcass characteristics, and carcass fat quality of growing-finishing pigs.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at Kansas State University approved the protocols used in these experiments.

General

Two experiments that involved a total of 576 pigs (TR4 ×1050; PIC, Hendersonville, TN) were conducted at the Kansas State University Swine Teaching and Research Center. The facility was a totally enclosed, environmentally controlled, mechanically ventilated barn. It had 2 identical rooms containing 40 pens (2.4 × 3.1 m) with adjustable gates facing the alleyway, allowing for 0.93 m^2 per pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder with 2 eating spaces (Farmweld, Teutopolis, IL) located in the fence line. Pens were located over a completely slatted concrete floor with a 1.2-m pit underneath for manure storage. The facility was also equipped with an automated feeding system (FeedPro; Feedlogic Corp., Willmar, MN) capable of delivering and recording diets as specified on an individual pen basis. The equipment provided pigs ad libitum access to feed and water.

Nutrient values used in diet formulation for corn, soybean meal, midds, and CWG were from the NRC (1998). For DDGS, AA concentration and standardized ileal digestible (**SID**) AA values were from Stein (2007), whereas Pedersen et al. (2007) demonstrated the ME of corn and DDGS are equal; thus, corn ME (3,420 kcal/kg) from the NRC (1998) was used.

Experiment 1

Pigs, Experimental Design, Diets, and Data Collection. Two hundred eighty-eight pigs (initial BW = 46.6 ± 1.0 kg) were used in an 84-d experiment to evaluate the effects of DDGS and increasing dietary midds on growing-finishing pig growth performance, carcass traits, and carcass fat quality. Pens of pigs were allotted in a complete randomized design to 1 of 4 treatments with 8 pigs per pen (4 barrows and 4 gilts) and 9 pens per treatment. Treatments included a corn-soybean meal-based control diet, the control with 30% DDGS, the DDGS diet with 10% midds, and the DDGS diet with 20% midds (Tables 1 and 2). Diets were fed in a meal form. Pigs were fed in 4 phases from approximately 46 to 67, 67 to 84, 84 to 101, and 101 to 131 kg BW for phases 1 to 4, respectively. Treatment diets were formulated to constant SID Lys:ME ratio in each phase. Diets were formulated to meet all requirement estimates (NRC, 1998).

Pigs were weighed by pen on d 0, 20, 36, 52, and 84 to determine ADG, which were the days of feed phase changes. Feed intake and G:F were determined from feed delivery data generated through the automated feeding system and the amount of feed remaining in the feeder for each pen on every weigh day.

On d 84, pigs were weighed and transported (approximately 204 km) to a packing plant (Triumph Foods Inc., St. Joseph, MO). Pigs had been individually tattooed according to pen number to allow for data retrieval by pen and carcass data collection at the packing plant. Hot carcass weights were measured immediately after evisceration, and each carcass was evaluated for percentage yield, backfat, and loin depth. Percentage yield was calculated by dividing HCW by BW obtained at the farm before transport to the packing plant. Fat depth and loin depth were measured with an optical probe (SFK, Herlev, Denmark) inserted between the 3rd and 4th last rib (counting from the ham end of the carcass) at a distance approximately 7.1 cm from the dorsal midline. Fat-free lean index (**FFLI**) was calculated according to National Pork Producers Council (2000) procedures. Jowl samples were also collected and analyzed by near

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

	Phase 1				Phase 2			
DDGS,[2] %:	0	30	30	30	0	30	30	30
Item Midds,[3] %:	0	0	10	20	0	0	10	20
Ingredient, %								
Corn	79.96	55.55	48.31	41.04	83.38	58.93	51.68	44.22
Soybean meal, 46.5% CP	17.43	12.12	9.34	6.57	14.29	8.95	6.17	3.48
DDGS	–	30.00	30.00	30.00	–	30.00	30.00	30.00
Midds	–	–	10.00	20.00	–	–	10.00	20.00
Monocalcium phosphate, 21% P	0.50	–	–	–	0.35	–	–	–
Limestone	0.98	1.28	1.28	1.30	0.95	1.18	1.18	1.30
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[4]	0.15	0.15	0.15	0.15	0.13	0.13	0.13	0.13
Trace mineral premix[5]	0.15	0.15	0.15	0.15	0.13	0.13	0.13	0.13
L-Lys×HCl	0.29	0.35	0.39	0.43	0.26	0.32	0.36	0.40
DL-Met	0.02	–	–	–	0.01	–	–	–
L-Thr	0.06	–	–	–	0.04	–	–	–
Phytase[6]	0.13	0.05	0.03	0.02	0.13	0.03	0.01	–
Total	100.02	100.00	100.00	100.01	100.02	100.02	100.01	100.01
Calculated analysis								
Standardized ileal digestible (SID) AA, %								
Lys	0.86	0.87	0.86	0.85	0.76	0.76	0.75	0.74
Met:Lys	28	34	34	34	29	37	37	37
Met + Cys:Lys	57	69	69	70	59	75	75	75
Thr:Lys	61	64	63	61	61	67	65	64
Trp:Lys	17	17	17	17	17	17	17	17
Total Lys, %	0.96	1.02	1.01	0.99	0.85	0.91	0.90	0.88
ME, kcal/kg	3,334	3,351	3,314	3,276	3,347	3,358	3,320	3,278
SID Lys:ME,g/Mcal	2.58	2.58	2.58	2.58	2.27	2.27	2.27	2.27
CP, %	15.2	18.9	18.6	18.3	14.0	17.6	17.4	17.1
Ca, %	0.55	0.55	0.55	0.56	0.50	0.50	0.50	0.55
P, %	0.45	0.45	0.51	0.56	0.41	0.44	0.49	0.55
Available P, %	0.28	0.28	0.28	0.28	0.24	0.24	0.24	0.26

[1]Phase 1 diets were fed from approximately 45 to 63.5 kg; and phase 2 diets were fed from 63.5 to 81 kg.

[2]DDGS = distillers dried grains with solubles.

[3]Midds = wheat middlings.

[4]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}.

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

[6]Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 600,533 phytase unts phytase/kg.

infrared spectroscopy (Multi Purpose Analyzer; Bruker, Billerica, MA) for iodine value using the equation of Cocciardi et al. (2009).

Chemical Analysis. Samples of midds (Archer Daniels Midland Co., Lincoln, NE) and DDGS (Hawkeye Gold, Menlo, IA) were collected at the time of feed manufacturing and combined into a single composite sample that was analyzed for moisture (method 934.01), CP (method 990.03), crude fat (method 920.39 A), crude fiber (method 978.10), ash (method 942.05), Ca (method 965.14/985.01), and P (method 965.17/985.01) using the AOAC International (2006) methods at a commercial laboratory (Ward Laboratories, Kearney, NE). Composite samples of midds and DDGS were also analyzed for complete AA profile [method 982.30 E (a, b, c); AOAC International, 2006] at the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO). Composite diet samples by treatment for each phase were measured for bulk density using a test weight apparatus and computerized grain scale (Seedburo Model 8800; Seedburo Equipment, Chicago, IL).

Experiment 2

Pigs, Experimental Design, Diets, and Data Collection. Two hundred eighty-eight pigs (initial BW = 42.3 ± 1.0 kg) were used in an 87-d study to determine the effects of midds and CWG on growth performance, carcass characteristics, and carcass fat quality of finishing pigs. Pens of pigs were randomly allotted to 1 of 6 dietary treatments with 8 pigs per pen (4 barrows and 4 gilts) and 6 pens per treatment. Dietary treatments were arranged in a 2 × 3 factorial with the main effects of

Table 2. Phase 3 and 4 diet composition (Exp. 1, as-fed basis)[1]

	Phase 3				Phase 4			
DDGS,[2] %:	0	30	30	30	0	30	30	30
Item, Midds,[3] %:	0	0	10	20	0	0	10	20
Ingredient, %								
Corn	86.04	61.54	54.29	46.78	88.03	63.59	56.18	47.88
Soybean meal, 46.5% CP	11.80	6.46	3.68	1.00	9.95	4.53	1.84	0.00
DDGS	–	30.00	30.00	30.00	–	30.00	30.00	30.00
Midds	–	–	10.00	20.00	–	–	10.00	20.00
Monocalcium phosphate, 21% P	0.23	–	–	–	0.18	–	–	–
Limestone	0.98	1.13	1.14	1.29	0.95	1.08	1.15	1.28
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[4]	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08
Trace mineral premix[5]	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08
L-Lys×HCl	0.24	0.30	0.34	0.38	0.22	0.29	0.32	0.33
DL-Met	–	–	–	–	–	–	–	–
L-Thr	0.03	–	–	–	0.03	–	–	–
Phytase[6]	0.13	0.02	–	–	0.13	–	–	–
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis								
Standardized ileal digestible (SID) AA, %								
Lys	0.68	0.68	0.67	0.67	0.62	0.62	0.61	0.61
Met:Lys	30	39	39	39	32	42	42	42
Met + Cys:Lys	62	80	80	81	65	85	85	87
Thr:Lys	62	70	68	66	64	72	71	71
Trp:Lys	17	17	17	17	17	17	17	17
Total Lys, %	0.76	0.82	0.81	0.80	0.70	0.76	0.75	0.74
ME, kcal/kg	3,353	3,417	3,325	3,280	3,358	3,366	3,327	3,283
SID Lys:ME,g/Mcal	2.03	2.03	2.03	2.03	1.85	1.85	1.85	1.85
CP, %	13.0	16.7	16.4	16.1	12.3	15.9	15.7	15.7
Ca, %	0.48	0.48	0.48	0.54	0.45	0.45	0.48	0.53
P, %	0.37	0.43	0.48	0.54	0.35	0.42	0.48	0.53
Available P, %	0.21	0.21	0.23	0.26	0.20	0.20	0.23	0.26

[1]Phase 3 diets were fed from approximately 81 to 99 kg; and Phase 4 diets were fed from 99 to 131 kg.

[2]DDGS = distillers dried grains with solubles.

[3]Midds = wheat middlings.

[4]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}.

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

[6]Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 600,533 phytase units phytase/kg .

added midds (0 or 20%) and CWG (0, 2.5, or 5%; Tables 3 and 4). Dietary treatments were corn-soybean meal-based with 15% DDGS and were fed in 4 phases. All diets were fed in a meal form and balanced to a similar SID Lys:ME ratio in each phase.

Wheat middlings (Archer Daniels Midland Co., Lincoln, NE) and DDGS (Abengoa, York, NE) samples were collected at the time of feed manufacturing and a composite sample was analyzed for nutrient content as described for Exp. 1. Diet samples were collected from each feeder and combined for a single composite sample by treatment for each phase to measure bulk density as described for Exp. 1.

Pigs and feeders were weighed on d 0, 21, 41, 60, and 87 to calculate ADG. Feed intake and G:F were determined from feed delivery data generated through the automated feeding system and the amount of feed remaining in the feeder for each pen on every weigh day.

On d 87, all pigs were weighed and transported (approximately 204 km) to a packing plant (Triumph Foods Inc.). Pigs were tattooed and carcass data was collected and analyzed as described in Exp. 1.

Statistical Analysis

For Exp.1 and 2, data were analyzed as a completely randomized design using the MIXED procedure (SAS Inst. Inc., Cary, NC) with treatment as the fixed effect and the pen as the experimental unit. Because HCW differed, it was used as a covariant for backfat, loin depth, and FFLI. In Exp. 1, linear and quadratic polynomial contrasts were used to determine the effects of increasing dietary midds. A single degree of freedom contrast

Table 3. Phase 1 and 2 diet composition (Exp. 2, as-fed basis)[1]

Item	Phase 1						Phase 2					
Wheat middlings, %:	0	0	0	20	20	20	0	0	0	20	20	20
Choice white grease, %:	0	2.5	5	0	2.5	5	0	2.5	5	0	2.5	5
Ingredient, %												
Corn	64.83	61.25	57.40	50.45	46.86	43.06	67.99	64.22	60.58	53.47	49.79	46.11
Soybean meal, 46.5% CP	17.73	18.81	20.13	12.17	13.25	14.57	14.76	16.00	17.16	9.28	10.52	11.68
Distillers dried grains with solubles	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Wheat middlings	–	–	–	20.00	20.00	20.00	–	–	–	20.00	20.00	20.00
Choice white grease	–	2.50	5.00	–	2.50	5.00	–	2.50	5.00	–	2.50	5.00
Monocalcium P, 21% P	0.30	0.30	0.30	–	–	–	0.30	0.30	0.30	–	–	–
Limestone	1.08	1.08	1.08	1.23	1.22	1.20	1.00	1.00	0.98	1.15	1.13	1.13
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[2]	0.15	0.15	0.15	0.15	0.15	0.15	0.13	0.13	0.13	0.15	0.13	0.13
Trace mineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.13	0.13	0.13	0.15	0.13	0.13
L-Lys×HCl	0.31	0.32	0.33	0.39	0.40	0.40	0.29	0.30	0.30	0.37	0.37	0.38
L-Thr	0.03	0.03	0.05	0.05	0.06	0.06	0.01	0.01	0.03	0.04	0.04	0.05
Phytase[4]	0.06	0.06	0.06	0.06	0.06	0.06	0.04	0.04	0.04	0.04	0.04	0.04
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis												
SID AA, %												
Lys	0.93	0.96	0.99	0.91	0.94	0.97	0.84	0.87	0.90	0.82	0.85	0.88
Met:Lys	30	29	28	29	29	28	31	30	30	31	30	29
Met + Cys:Lys	61	59	58	61	59	58	64	62	61	64	63	61
Thr:Lys	62	62	62	62	62	62	62	62	62	62	62	62
Trp:Lys	17	17	17	17	17	17	17	17	17	17	17	17
Total Lys, %	1.06	1.10	1.13	1.03	1.06	1.10	0.97	1.00	1.03	0.94	0.97	1.00
ME, kcal/kg	3,344	3,457	3,571	3,274	3,386	3,501	3,351	3,463	3,578	3,278	3,393	3,508
SID Lys:ME/Mcal	2.78	2.78	2.78	2.78	2.78	2.78	2.51	2.51	2.51	2.51	2.51	2.51
CP, %	18.15	18.36	18.66	17.61	17.82	18.12	17.01	17.27	17.52	16.50	16.77	17.01
Ca, %	0.55	0.55	0.55	0.55	0.55	0.55	0.51	0.51	0.51	0.51	0.51	0.51
P, %	0.47	0.47	0.47	0.52	0.52	0.51	0.46	0.46	0.46	0.51	0.50	0.50
Available P, %	0.28	0.28	0.28	0.28	0.28	0.28	0.25	0.25	0.25	0.25	0.25	0.25

[1]Phase 1 diets were fed from approximately 42 to 63.5 kg. Phase 2 diets were fed from 63.5 to 81.6 kg BW. Nutrient values used in diet formulation for corn, soybean meal, wheat middlings, and choice white grease were from the NRC (1998). For distillers dried grains with soluble (DDGS), AA concentration and standardized ileal digestible (SID) AA were from Stein (2007), whereas corn ME from the NRC (1998; 3,420 kcal/kg) was used.

[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; 11 g 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 600,533 phytase units phytase/kg.

was used to compare pigs fed the control diet with pigs fed the diet containing 30% DDGS without midds. In Exp. 2, the main effects of midds and added CWG and their interactions were assessed. Linear and quadratic contrasts were used to determine the effects of increasing dietary CWG. Results were considered significant at $P \leq 0.05$ and considered trends at $P \leq 0.10$.

RESULTS

Chemical Analysis

Analysis of nutrients in DDGS and midds were verified to be generally similar to values used in formulation (Tables 5 and 6), and we do not believe the differences affected the results or data interpretation of the experiments. Bulk density tests showed that adding dietary DDGS and midds decreased diet bulk density, but adding CWG had no effect (Tables 7 and 8).

Experiment 1

Overall (d 0 to 84), pigs fed increasing midds had decreased ADG (linear; $P = 0.02$) and G:F (linear; $P < 0.01$; Table 9), but ADFI did not differ among treatments. As the dietary concentration of midds increased, final BW tended to decrease (linear, $P = 0.07$). Feeding 30% DDGS did not influence growth performance. For carcass traits, increasing the dietary concentration of midds decreased (linear, $P < 0.01$) carcass yield and HCW and tended to decrease (linear, $P = 0.06$) loin depth. Pigs fed midds also had decreased (quadratic, $P = 0.02$)

Table 4. Phase 3 and 4 diet composition (Exp. 2, as-fed basis)[1]

	Phase 3						Phase 4					
Wheat middlings, %:	0	0	0	20	20	20	0	0	0	20	20	20
Item Choice white grease, %:	0	2.5	5	0	2.5	5	0	2.5	5	0	2.5	5
Ingredient, %												
Corn	70.81	67.30	63.73	56.41	52.93	49.29	73.59	70.19	66.76	59.08	55.64	52.09
Soybean meal, 46.5% CP	12.04	13.04	14.12	6.51	7.48	8.60	9.35	10.27	11.19	3.95	4.87	5.91
Distillers dried grains with solubles	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Wheat middlings	–	–	–	20.00	20.00	20.00	–	–	–	20.00	20.00	20.00
Choice white grease	–	2.50	5.00	–	2.50	5.00	–	2.50	5.00	–	2.50	5.00
Monocalcium P, 21% P	0.30	0.30	0.30	–	–	–	0.30	0.30	0.30	–	–	–
Limestone	1.00	1.00	0.98	1.13	1.13	1.13	0.98	0.95	0.95	1.10	1.10	1.10
Salt	0.35	0.35	0.35	0.35	0.35	0.35	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	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix[3]	0.10	0.10	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08	0.08	0.08
L-Lys×HCl	0.27	0.27	0.28	0.35	0.35	0.36	0.25	0.25	0.26	0.32	0.33	0.33
L-Thr	0.01	0.02	0.02	0.03	0.04	0.05	–	0.01	0.01	0.02	0.03	0.04
Phytase[4]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis												
SID AA, %												
Lys	0.75	0.78	0.80	0.74	0.76	0.79	0.67	0.69	0.71	0.65	0.68	0.70
Met:Lys	33	32	31	33	32	31	35	34	33	35	34	33
Met + Cys:Lys	68	66	64	68	66	65	73	71	69	74	71	69
Thr:Lys	64	64	64	64	64	64	65	65	65	65	65	65
Trp:Lys	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
Total Lys, %	0.87	0.90	0.93	0.85	0.87	0.90	0.78	0.81	0.83	0.76	0.78	0.80
ME, kcal/kg	3,353	3,468	3,580	3,283	3,397	3,510	3,358	3,472	3,585	3,280	3,399	3,514
SID Lys:ME/Mcal	2.24	2.24	2.24	2.24	2.24	2.24	1.99	1.99	1.99	1.99	1.99	1.99
CP, %	15.96	16.14	16.34	15.44	15.60	15.82	14.92	15.07	15.21	14.44	14.59	14.78
Ca, %	0.50	0.50	0.50	0.50	0.50	0.50	0.48	0.48	0.48	0.48	0.48	0.48
P, %	0.45	0.45	0.45	0.50	0.49	0.49	0.44	0.44	0.43	0.49	0.48	0.48
Available P, %	0.23	0.23	0.23	0.23	0.23	0.23	0.22	0.22	0.22	0.22	0.22	0.22

[1]Phase 3 diets were fed from approximately 81.6 to 100 kg; and Phase 4 diets were fed from 100 to 133 kg BW. Nutrient values used in diet formulation for corn, soybean meal, wheat middlings, and choice white grease were from the NRC (1998). For distillers dried grains with soluble (DDGS), AA concentration and standard ilal digestible (SID) AA digestibility were from Stein (2007), whereas corn ME from the NRC (1998; 3,420 kcal/kg) was used.

[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; 11 g 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 600,533 phytase units phytase/kg.

backfat depth and increased (quadratic; $P < 0.01$) FFLI. Although feeding 30% DDGS did not affect growth performance, it resulted in decreased carcass yield ($P = 0.03$) and backfat depth ($P < 0.01$) with increased FFLI ($P = 0.02$) and jowl fat iodine value ($P < 0.01$).

Experiment 2

No CWG × midds interactions were observed (Table 10). Overall (d 0 to 87), feeding 20% dietary midds decreased ($P < 0.01$) ADG and G:F (Table 11). Pigs fed diets with increasing CWG had increased ADG (linear, P < 0.01; quadratic, $P = 0.03$) and G:F (linear, $P < 0.01$). Feed intake was not affected by the addition of 20% dietary midds or up to 5% of CWG. Pigs fed diets containing 20% midds had decreased ($P < 0.01$) final BW, but a trend for increased final BW (linear, $P = 0.09$) was observed as dietary CWG increased.

For carcass traits, feeding 20% midds decreased carcass yield ($P = 0.04$), HCW ($P < 0.01$), backfat depth ($P = 0.04$), and loin depth ($P < 0.01$). Furthermore, feeding 20% midds increased jowl fat iodine value ($P < 0.01$). In addition, pigs fed CWG had a tendency for increased (linear, $P = 0.06$) backfat depth, increased (linear, $P < 0.01$) jowl fat iodine value, and decreased (linear, $P < 0.05$) FFLI.

DISCUSSION

In both of the current experiments, it was observed that pigs fed diets with varying amounts of midds had decreased ADG and G:F with no change in ADFI. These

Table 5. Chemical composition of distillers dried grains with solubles (DDGS) and wheat middlings (Midds; Exp. 1, as-fed basis)

Item	DDGS[1]	Midds[2]
DM, %	90.98	89.72
CP, %	27.0 (27.7)[3]	14.7 (15.9)
Crude fat, %	11.0 (10.7)	3.8 (4.2)
Crude fiber, %	9.7 (7.3)	8.2 (7.0)
ADF, %	12.8	11.4
NDF, %	24.1	32.0
Ca, %	0.32 (0.20)	0.32 (0.12)
P, %	0.78 (0.77)	1.09 (0.93)
Indispensable AA, %		
Arg	1.24	1.11
His	0.80	0.45
Ile	1.08 (1.03)	0.53 (0.53)
Leu	3.26 (2.57)	1.03 (1.06)
Lys	0.84 (0.62)	0.72 (0.57)
Met	0.53 (0.50)	0.24 (0.26)
Phe	1.38	0.64
Thr	1.03 (0.94)	0.53 (0.51)
Trp	0.21 (0.25)	0.20 (0.20)
Val	1.47 (1.30)	0.77 (0.75)

[1]DDGS (Hawkeye Gold, Menlo, IA) AA values from Stein (2007).

[2]Wheat middlings (Archer Daniels Midland Co., Lincoln, NE) nutrient and AA values from NRC (1998).

[3]Values in parentheses indicate those used in diet formulation.

results agree with those reported by Feoli et al. (2006) and Cromwell et al. (1992) who also observed decreased ADG and G:F when midds were increased in the diet with no change in feed intake. The increase in NDF content in diets containing both midds and DDGS may have limited the ability of the pigs to consume enough feed to overcome the lower energy concentration in the diets containing midds.

Adding 5% CWG to the diet containing 20% midds resulted in ADG and G:F that was not different from that obtained for the diet without midds or added CWG. The ME of the high-fat, 20% midds diet would indicate that pigs fed this diet should have had improved G:F, indicating that the diet ME may have been overestimated in the midds diets, or that other factors may have prevented further improvement.

Research by Just (1982) evaluated the effects of increasing dietary fiber on NE value and growth performance of growing swine and reported that increasing NDF in swine diets reduced digestibility of all nutrients except soluble carbohydrates and increased the proportion of nutrients in the hindgut. Turlington (1984) observed an increase in gut fill and colon contents when dietary fiber was increased. Furthermore, Just (1982) reported decreased ME use and increased excretion of non-available nutrients when NDF content increased in the diet. Increased crude fiber can increase the amount of energy excreted through urine N, which may reduce the use of absorbed energy (Just, 1982).

Table 6. Chemical composition of distillers dried grains with solubles (DDGS) and wheat middlings (Midds; Exp.2, as-fed basis)

Item	DDGS[1]	Midds[2]
DM, %	91.3	90.4
CP, %	27.7 (27.7)[3]	14.6 (15.9)
Crude fat, %	11.0 (10.7)	3.9 (4.2)
Crude fiber, %	9.5 (7.3)	8.4 (7.0)
ADF, %	11.0	10.2
NDF, %	27.1	34.0
Ca, %	0.15 (0.20)	0.14 (0.12)
P, %	0.80 (0.77)	1.00 (0.93)

[1]DDGS obtained from Hawkeye Gold (Menlo, IA).

[2]Midds obtained from Archer Daniels Midland Co. (Lincoln, NE) and composition values from NRC (1998).

[3]Values in parentheses indicate those used in diet formulation.

Some theory behind reduced ME use in high-fiber diets is thought to be the increased proportion of nutrients transferred to the hindgut. Increased crude fiber can increase the passage rate of nutrients through the digestive tract and decrease digestion in the small intestine; therefore, a larger proportion of carbohydrates is fermented in the hindgut, synthesizing VFA (acetic acid, butyric acid, and propionic acid), which likely have a lower metabolic efficiency than glucose absorbed in the small intestine (Just, 1982). The additive effects of increased heat from fermentation, increased gas production, and increased protein excretion from urea can result in decreased energy use. This may explain why pigs fed the diet with 5% added CWG and 20% midds (3,501, 3,508, 3,510, and 3,514 kcal ME/kg in phase 1, 2, 3, and 4, respectively) had similar growth performance and final BW to those pigs fed the diet with no added fat and no midds, which has less ME (3,344, 3,351, 3,353, and 3,358 kcal ME/kg in phase 1, 2, 3, and 4, respectively).

Shaw et al. (2002) reported that 30% midds could be included in grow-finish diets before a reduction in

Table 7. Bulk density of diets containing distillers dried grains with solubles (DDGS) and wheat middlings (Midds; Exp.1, as-fed basis)[1,2,3]

		Treatments			
DDGS, % :		0	30	30	30
Item	Midds, %:	0	0	10	20
Phase 1[4]		–	–	–	–
Phase 2		638	609	554	480
Phase 3		658	621	511	532
Phase 4		645	613	584	528

[1]576 pigs (TR4 × 1050, PIC Hendersonville, TN; 45.4 kg initial BW) were used in this 84-d study with 8 pigs per pen and 9 pens per treatment.

[2]Bulk density of a material represents the mass per unit volume (g/L).

[3]Diet samples collected from each feeder and combined for a single composite sample by treatment and phase.

[4]Phase 1 was d 0 to 20; Phase 2 was d 20 to 36; Phase 3 was d 36 to 52; and Phase 4 was d 52 to 84.

Table 8. Bulk density of diets containing choice white grease (CWG) and wheat middlings (Midds; Exp.2, as-fed basis)[1,2,3]

	Treatments					
Midds, %:	0	0	0	20	20	20
Item CWG, %:	0	2.5	5.0	0	2.5	5.0
Phase 1[4]	660	639	639	584	557	551
Phase 2	656	635	635	542	538	533
Phase 3	659	659	658	533	525	522
Phase 4	665	663	663	560	551	557

[1]288 pigs (TR4 × 1050: PIC Hendersonville, TN; 42.3 kg initial BW) were used in this 87-d study with 8 pigs per pen and 6 replications per diet.

[2]Bulk density of a material represents the mass per unit volume (g/L).

[3]Diet samples collected from each feeder and combined for a single composite sample by treatment and phase.

[4]Phase 1 was d 0 to 21; Phase 2 was d 21 to 41; Phase 3 was d 41 to 60; and Phase 4 was d 60 to 87.

growth performance was observed. Other research (Erickson et al., 1985; Cromwell et al., 1992) observed a decrease in performance when as little as 10% midds was added to the diet. The effects of wheat middlings on growth and carcass data of finishing pigs can vary depending on nutrient content as well as bulk density. Differences among trials may be explained by the variation that can occur between midds sources and even variation within batches of midds. Differences in wheat type, grade, and wheat processing specifications can affect the components of the wheat kernel that are used for midds. In addition, midds nutrient concentration can vary depending on the objectives of the milling process (Blasi et al., 1998).

Increased dietary midds resulted in light bulk density of the diets, whereas CWG had no effect. A decrease in bulk density may result in increased gut fill because of the greater fiber concentration. Because midds products vary, research has evaluated midds quality, bulk density in particular. Cromwell et al. (2000) suggested bulk density may not only affect gut fill, but also be used as a general indicator for assessing the quality of midds because bulk density provides an estimate of the amount of bran and flour in midds products. Wheat middlings with a light bulk density typically consist of more bran material, and, therefore, a greater fiber, protein, and phosphorus content than heavier midds consisting of starchier endosperm parts of the kernel. This theory agrees with earlier data obtained by Cromwell et al. (1992), in which finishing pigs were fed diets differing in bulk densities with light (34% NDF, 15.1% CP, and 0.65% Lys) or heavy (30% NDF, 14.0% CP, and 0.58% Lys) midds in increasing amounts. Feeding light midds to pigs resulted in poorer growth performance; however, growth performance of pigs was negatively affected by midds regardless of bulk density.

Data from Exp. 1 agree with results of research indicating that up to 30% DDGS can be included in finishing swine diets without a negative effect on performance (Stein, 2007; Stein and Shurson, 2009). Although feeding 30% DDGS did not affect growth performance, it did result in decreased carcass yield and softer fat as indicated by increased jowl fat iodine value. In previous research, DDGS also has been reported to increase fat iodine value (Whitney et al., 2006; Benz et al., 2010). Whitney et al. (2006) reported that belly fat iodine value

Table 9. Effects of distillers dried grains with solubles (DDGS) and wheat middlings (Midds) on growth performance, carcass characteristics, and carcass fat quality of growing-finishing pigs (Exp. 1)[1]

	Treatment					*P*-value		
DDGS, %:	0	30	30	30			Midds	
Item Midds, %:	0	0	10	20	SEM	DDGS[2]	Linear	Quadratic
Initial BW, kg	46.6	46.6	46.6	46.6	0.60	0.97	0.96	1.00
d 0 to 84								
ADG, kg	1.051	1.038	1.005	0.991	0.014	0.51	0.02	0.57
ADFI, kg	3.22	3.11	3.10	3.09	0.046	0.12	0.68	0.95
G:F	0.327	0.333	0.324	0.322	0.003	0.11	0.01	0.32
Final BW, kg	134.9	133.8	131.0	129.8	1.50	0.61	0.07	0.65
Carcass characteristics								
Carcass yield,[3] %	74.2	73.4	72.7	72.1	0.27	0.03	0.01	0.94
HCW, kg	100.1	98.1	95.3	93.6	1.12	0.22	0.01	0.65
Backfat depth,[4] mm	24.8	22.9	24.0	21.9	0.58	0.01	0.24	0.02
Loin depth,[4] mm	61.2	61.5	59.9	60.0	0.56	0.73	0.06	0.17
FFLI[4, 5]	48.2	49.3	48.6	49.8	0.34	0.02	0.29	0.01
Jowl fat iodine value	70.6	76.5	76.0	77.4	0.56	0.01	0.29	0.19

[1]A total of 288 pigs (TR4 × 1050, PIC Hendersonville, TN) were used in an 84-d trial with 8 pigs per pen and 9 replications per diet.

[2]Contrast: control vs. 30% DDGS with 0% midds diet.

[3]Percentage yield was calculated by dividing HCW by BW obtained before transport to the packing plant.

[4]Data analyzed by using HCW value as a covariate.

[5]FFLI = fat-free lean index.

Table 10. Interactive effects of wheat middlings (Midds) and choice white grease (CWG) on growth performance, carcass characteristics, and carcass fat quality of growing-finishing pigs (Exp. 2)[1]

	Treatment							
Midds, %:	0	0	0	20	20	20		*P*-value
Item CWG, %:	0	2.5	5.0	0	2.5	5.0	SEM	CWG × Midds
Initial BW, kg	42.3	42.4	42.3	42.3	42.3	42.3	1.3	1.00
d 0 to 87								
ADG, kg	1.052	1.049	1.084	0.988	0.983	1.040	0.013	0.64
ADFI, kg	3.06	3.03	3.04	3.07	2.97	3.00	0.05	0.76
G:F	0.344	0.347	0.357	0.322	0.332	0.347	0.004	0.33
Final BW, kg	133.8	135.2	136.9	128.2	128.9	132.8	2.2	0.87
Carcass characteristics								
Carcass yield,[2] %	73.3	73.9	73.4	72.8	72.9	72.8	0.4	0.82
HCW, kg	98.0	99.8	100.5	93.4	94.0	96.7	1.8	0.84
Backfat depth,[3] mm	21.3	22.7	22.2	20.0	20.3	21.8	0.7	0.35
Loin depth,[3] mm	65.4	64.0	64.1	61.6	61.0	62.9	0.7	0.14
FFLI[3,4]	50.6	49.7	50.0	51.1	50.9	50.1	0.4	0.41
Jowl iodine value	71.6	72.4	72.3	73.8	73.7	75.1	0.3	0.12

[1]288 pigs (TR4 × 1050, PIC Hendersonville, TN) were used in an 87-d study with 8 pigs per pen and 6 replications per diet.

[2]Percentage yield was calculated by dividing HCW by BW obtained before transport to the packing plant.

[3]Data analyzed by using HCW value as a covariate.

[4]FFLI = fat-free lean index.

increased 1.7 g/100 g for every 10% DDGS in grow-finish diets. The increase in iodine value is due to the increased unsaturated fat provided by DDGS. Boyd et al. (1997), Averette-Gatlin et al. (2003), and Weber et al. (2006) also demonstrated that increased dietary unsaturated fat increased carcass iodine value.

The effect of midds on jowl fat iodine value has not been previously evaluated. In Exp. 2, pigs fed 20% midds had increased jowl fat iodine value even when DDGS amount was constant at 15%; however, increasing dietary midds had no effect on jowl fat iodine value in Exp. 1. Bergstrom et al. (2011) reported pigs with slower growth rates and less backfat had increased iodine value, which agrees with the observations in Exp. 2.

In the current study, carcass yield was reduced when dietary DDGS was fed. Other studies have reported decreased yield with the addition of dietary DDGS (Hinson et al., 2007; Xu et al., 2010; Linneen et al., 2008). This may be due to the greater fiber content of DDGS compared with corn. The high fiber content leads to increased gut fill, thus, increased visceral weight, which is not included in carcass yield measurement (Turlington, 1984).

Table 11. Effects of wheat middlings (Midds) and choice white grease (CWG) on growth performance, carcass characteristics, and carcass fat quality of growing-finishing pigs (Exp. 2)[1]

									P-value			
									Main effects		Added CWG	
	Midds, %		CWG, %			SEM						
Item	0	20	0	2.5	5.0	Midds	CWG		Midds	CWG	Linear	Quadratic
Initial BW, kg	42.3	42.3	42.3	42.3	42.3	0.8	0.9		0.98	1.00	0.98	0.98
d 0 to 87												
ADG, kg	1.062	1.004	1.020	1.016	1.062	0.008	0.009		0.01	0.01	0.01	0.03
ADFI, kg	3.04	3.01	3.07	3.00	3.02	0.03	0.03		0.40	0.31	0.29	0.28
G:F	0.349	0.334	0.333	0.339	0.352	0.002	0.003		0.01	0.01	0.01	0.32
Final BW, kg	135.3	130.0	131.0	132.1	134.8	1.2	1.5		0.01	0.21	0.09	0.64
Carcass characteristics												
Carcass yield,[2] %	73.5	72.8	73.0	73.4	73.1	0.2	0.3		0.04	0.67	0.86	0.39
HCW, kg	99.5	94.7	95.7	96.9	98.6	1.0	1.3		0.01	0.29	0.12	0.89
Back fat,[3] mm	22.1	20.7	20.6	21.5	22.0	0.4	0.5		0.04	0.16	0.06	0.77
Loin depth,[3] mm	64.5	61.8	63.5	62.5	63.5	0.4	0.5		0.01	0.22	1.00	0.08
FFLI[3,4]	50.1	50.7	50.8	50.3	50.0	0.2	0.3		0.11	0.13	0.05	0.65
Jowl iodine value	72.1	74.2	72.7	73.1	73.7	0.2	0.2		0.01	0.02	0.01	0.66

[1]288 pigs (TR4 × 1050; PIC Hendersonville, TN) were used in an 87-d study with 8 pigs per pen and 6 replications per diet.

[2]Percentage yield was calculated by dividing HCW by BW obtained before transport to the packing plant.

[3]Data analyzed by using HCW value as a covariate.

[4]FFLI = fat-free lean index.

Wheat middlings have been reported to affect pig gut fill because of their high fiber content, thus, reducing carcass yield (Shaw et al., 2002). Just (1982) reported a 0.34-kg increase in gut fill per 1% increase in crude fiber for pigs that had been withdrawn from feed (approximately 12 h) before time of slaughter; however, if those pigs had been fed the same day they were killed, the gut fill would have been greater. Results of the current experiments also agree with Just (1982) who reported that feeding pigs diets with increased fiber resulted in decreased backfat depth, protein deposition, and loin depth.

Research with other wheat milling co-products such as wheat shorts (Beames and Natoli, 1969; Patience et al., 1977) also reported decreased carcass yield. Young (1980) obtained a shrunk weight of pigs to reduce the influence of gut fill on yield to evaluate other possibilities of decreased carcass yield in pigs fed wheat shorts. Calculations of ADG and G:F based on the shrunk weight revealed a decline in the performance of pigs fed increasing amounts of dietary wheat shorts. Reduction in carcass traits can be attributed to the combination of increased gut fill and visceral weight and decreased BW before slaughter.

In the current study, CWG was added to minimize the negative effects of dietary midds on performance and carcass traits. Although adding dietary CWG to diets with midds resulted in growth performance that was not different from pigs fed corn-soybean meal diets, a reduction in carcass yield was observed in pigs fed all midds-containing diets regardless of dietary fat addition. These results are consistent with Shaw et al. (2002), who included 30% dietary midds with added CWG to finishing pig (65 to 107 kg BW) diets. Thus, the cost of ingredients and impact on yield must be taken into account when contemplating the addition of dietary fat to diets containing midds. Just (1982) concluded that pigs fed high-fiber diets may have similar daily BW gain, but BW should be adjusted for gut fill to obtain a similar carcass weight.

In conclusion, these data indicate that reduced dietary energy and decreased bulk density of diets containing midds reduced pig performance and carcass yield and increased jowl fat iodine value. Increasing diet energy with CWG helped mitigate some of the negative effect on live performance; however, additional energy from CWG did not eliminate the negative impact of midds on carcass yield and carcass weight.

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