

Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern Midwestern ethanol plant¹

M. H. Whitney,* G. C. Shurson,*² L. J. Johnston,† D. M. Wulf,‡ and B. C. Shanks‡

*Department of Animal Science, University of Minnesota, St. Paul 55108; †Department of Animal Science, University of Minnesota, Morris 56267; and ‡Department of Animal and Range Science, South Dakota State University, Brookings 57007

ABSTRACT: A growth performance and carcass evaluation study was conducted to determine the maximal inclusion rate of corn distillers dried grain with solubles (DDGS) in grower-finisher pig diets when formulated on a total AA basis. A total of 240 (28.4 ± 0.8 kg of BW) crossbred pigs [(Yorkshire × Landrace) × Duroc] were allotted randomly within sex and weight outcome groups to 1 of 24 pens. Pens were assigned randomly within the initial BW groups to 1 of 4 dietary treatment sequences in a 5-phase grower-finisher feeding program in a 4 × 3 factorial arrangement of treatments. The inclusion level of DDGS (0, 10, 20, or 30%) in the diet and the initial BW class [low (23.2 kg), medium (28.1 kg), or high (33.8 kg)] served as the main factors for the grower-finisher performance study. All diets were formulated to contain similar concentrations of total Lys, ME, calcium, and phosphorus within each phase. Pigs were slaughtered and carcass data were collected when the average BW of pigs in a pen reached 114 ± 2.25 kg. Dietary treatment and initial weight groups did not interact for any response variables, and only the main effects of dietary treatment are presented. Pigs fed the 20 or 30% DDGS diets had reduced ADG ($P < 0.05$) compared with that of the 0 or 10% DDGS groups, but ADFI was unaffected by dietary

treatment. Gain:feed decreased when pigs were fed 30% DDGS ($P < 0.05$) compared with the 0, 10, and 20% DDGS dietary inclusion levels. Loin depth was lower in pigs fed the 30% DDGS diets ($P < 0.05$), but backfat depth and percentage of carcass lean did not differ among treatments. Iodine number of carcass fat increased linearly ($P < 0.01$) with increasing dietary DDGS concentration, and belly firmness adjusted for belly thickness was reduced ($P < 0.05$) for pigs fed the 30% DDGS diets compared with pigs fed the 0 or 20% DDGS diets. Color measurements, ultimate pH, and visual evaluations (color, firmness, and marbling scores) of the LM did not differ among treatments. Cooking loss, 24-h drip loss, and total moisture loss were not affected by DDGS in the diets. However, differences were detected between 0 and 20% DDGS treatments for 11-d purge loss ($P < 0.05$). Dietary treatment did not affect Warner-Bratzler shear force of cooked loin chops. Results from this study indicate that when diets for grower-finisher pigs are formulated on a total AA basis, less than 20% DDGS should be included in the diet for optimal performance and carcass composition. Feeding DDGS in swine finishing diets did not have any detrimental effects on pork muscle quality.

Key words: carcass, distillers dried grain with solubles, growth, swine

©2006 American Society of Animal Science. All rights reserved.

J. Anim. Sci. 2006. 84:3356–3363
doi:10.2527/jas.2006-099

INTRODUCTION

Poor amino acid balance and digestibility have resulted in conservative and somewhat variable recommendations involving maximal inclusion rates of corn

distillers dried grain with solubles (DDGS) in grower-finisher pig diets. Weigel et al. (1997) recommended no more than 7.5% DDGS be used in diets for growing pigs (18 to 54 kg of BW) and no more than 10% DDGS be used in diets for finisher pigs (54 kg of BW to market). Other authors (Wahlstrom and German, 1968; Cromwell et al., 1984; Harper and Forsyth, 1998) suggested that DDGS can serve as a satisfactory energy and protein source in grower-finisher pig diets at concentrations up to 10%. In some studies (Harmon, 1975; Cromwell et al., 1983), diets containing 20% DDGS supported

¹We gratefully acknowledge the financial support of the Midwest DDGS Association.

²Corresponding author: shurs001@umn.edu

Received February 18, 2006.

Accepted July 19, 2006.

equivalent BW gain and feed efficiency compared with pigs fed corn-soybean meal diets, whereas Wahlstrom and Libal (1969) found reduced performance when pigs consumed diets containing 20% DDGS.

Modern ethanol plants generally produce DDGS that has greater concentrations of fat, Lys, and ME (Spiehs et al., 2002) and improved digestibility of phosphorus (Whitney and Shurson, 2001) compared with values published in NRC (1998), which are based on DDGS produced in plants that were built before 1990. Furthermore, Whitney et al. (2000) demonstrated that digestible Lys, Thr, and Trp concentrations in high-quality corn DDGS produced by modern ethanol plants are higher than values published in NRC (1998). Increased digestibility of AA indicates greater inclusion rates of high-quality DDGS may be possible before requiring the addition of crystalline AA to maintain proper AA balance.

Thus, a growth performance study was conducted to determine if adding increasing amounts of high-quality corn DDGS to grower-finisher diets in a phase feeding program will support growth performance and carcass quality similar to that obtained with diets based on corn and soybean meal.

MATERIALS AND METHODS

Animals and Dietary Treatments

The experimental protocol used in this study was approved by the University of Minnesota Institutional Animal Care and Use Committee. A total of 240 cross-bred pigs (70.4 ± 5.3 d of age) with an initial BW of 28.4 ± 0.8 kg were allotted randomly within sex and weight outcome groups to 1 of 24 pens, and pens were assigned randomly within the initial BW groups to 4 diets in a 4 × 3 factorial arrangement of treatments. The inclusion level of DDGS (0, 10, 20, or 30%) in the diet and the initial BW class [low (23.2 kg), medium (28.1 kg), or high (33.8 kg)] served as the main factors.

A 5-phase grower-finisher feeding program was utilized to evaluate growth performance and carcass characteristics. Target BW of the pigs were 23 to 40, 40 to 54, 54 to 72, 72 to 91, and 91 to 114 kg for phases 1 through 5, respectively. Diet changes were made on an individual pen basis, when the average BW of pigs in the pen was within 2.25 kg of the target BW for each phase.

Experimental diet composition and analyzed nutrient concentrations are presented for grower and finisher periods in Tables 1 and 2, respectively. Experimental diets within each phase of growth were formulated to contain similar concentrations of total Lys, ME, Ca, total P, and supplemental vitamins and trace minerals. Total AA values of DDGS were obtained from Spiehs et al. (2002) and were used in the formulation of experimental diets.

Distillers dried grain with solubles was sourced from a newer (built after 1990) ethanol plant (Al-Corn, Clare-

mont, MN) because it produced one of the most consistent products over a 3-yr period in our previous industry survey (Spiehs et al., 2002). This consistency was important because storage space was not available to purchase and store 1 batch of DDGS for use throughout the entire study. Two batches of DDGS were purchased to complete this experiment. Because of similar storage space constraints for other bulk ingredients (corn and soybean meal), experimental diets were formulated and mixed according to a standard matrix of nutrient content very similar to diet formulation approaches used in the commercial feed industry.

The ME values used in diet formulation were 3,776 kcal/kg (Spiehs et al., 2002) and 7,234 kcal/kg (NRC, 1982) for DDGS and soybean oil, respectively. The analyzed composition of DDGS used in this study was: 23.9% CP, 0.68% Lys, 10.3% crude fat, 0.2% Ca, and 0.82% P. Dietary total Lys concentrations were formulated to be 1.10, 1.00, 0.85, 0.72, and 0.64% for phases 1 to 5, respectively, based on mixed-sex pigs averaging 0.77 kg of ADG, 0.32 G:F, and 52% lean (NRC, 1998). All diets were formulated to meet or exceed a minimum ratio relative to Lys of 100, 55, 65, and 20% for total Lys, Met + Cys, Thr, and Trp, respectively, and contained 0.15% crystalline Lys. Soybean oil was added to the control diets at a rate of 4, 4, 3, 1.5, and 1.5% for phases 1 through 5, respectively. The greater amounts of soybean oil used in phases 1 through 3 were primarily to provide ample supplemental energy to support optimal growth, whereas the lower concentrations used during phases 4 and 5 were primarily for dust control. Because DDGS contains approximately 10% crude fat, decreasing amounts of soybean oil were added as DDGS inclusion level increased in the diet, providing similar dietary ME concentration and preventing total dietary fat concentrations from exceeding 7.5%. The vitamin-trace mineral premix was prepared and delivered monthly.

Feed samples were obtained from each batch of feed manufactured and frozen at -20°C until laboratory analysis could be performed. At the end of each phase, samples from each batch of feed mixed were combined within experimental diet and subsampled for nutrient analysis. A portion of this subsample was submitted for proximate and mineral analysis (AOAC, 1998; Iowa Testing Laboratories, Eagle Grove, IA). Another portion of the subsample was submitted for AA analysis by HPLC procedures (Experiment Station Chemical Laboratory, University of Missouri, Columbia).

Growth and Carcass Data Collection

Pigs were housed in an environmentally controlled, total confinement building. Pens measured 1.6 × 4.5 m and provided approximately 7.0 m² of totally slotted floor space. Each pen was equipped with one 4-space feeder and 1 nipple drinker. Pigs were allowed ad libitum access to feed and water throughout the experiment. Pigs were weighed, and feed disappearance was

Table 1. Composition of the experimental grower diets (as-fed basis)

Item	Early grower diet ¹				Late grower diet ²			
	DDGS ³ inclusion, %							
	0	10	20	30	0	10	20	30
Ingredient, %								
Corn	66.05	58.70	51.55	44.39	69.90	62.40	55.20	47.85
Soybean meal (46% CP)	27.25	25.25	23.00	20.75	23.50	21.50	19.25	17.25
Soybean oil	4.00	3.50	3.05	2.56	4.00	3.60	3.15	2.65
DDGS	0.00	10.00	20.00	30.00	0.00	10.00	20.00	30.00
Dicalcium phosphate	1.15	0.85	0.50	0.20	1.15	0.85	0.55	0.25
Limestone	0.85	1.00	1.20	1.40	0.75	0.95	1.15	1.30
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin trace mineral premix ⁴	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lysine·HCl	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Analyzed composition								
Ca, %	0.70	0.76	0.68	0.70	0.73	0.70	0.67	0.70
P, %	0.59	0.61	0.58	0.59	0.58	0.61	0.58	0.57
CP, %	17.7	18.2	19.6	19.8	17.1	17.8	19.2	20.2
Lys, %	0.90	0.98	1.01	1.06	1.06	1.04	1.02	1.04
Met and Cys, %	0.51	0.64	0.70	0.73	0.59	0.65	0.67	0.74
Thr, %	0.58	0.69	0.74	0.76	0.64	0.68	0.74	0.79
Trp, %	0.20	0.18	0.21	0.20	0.18	0.22	0.20	0.20

¹Diets were formulated to contain 3,435 kcal/kg of ME, 1.10% total Lys, 0.65% Ca, and 0.55% total P for pigs weighing 27 to 40 kg.

²Diets were formulated to contain 3,445 kcal/kg of ME, 1.00% total Lys, 0.62% Ca, and 0.54% total P for pigs weighing 40 to 54 kg.

³Distillers dried grain with solubles.

⁴Vitamin-trace mineral premix that supplied the following nutrients per kilogram of feed: 3,667 IU of vitamin A as retinyl acetate; 616 IU of vitamin D₃; 15 IU of vitamin E as DL- α -tocopherol acetate; 2.4 mg of vitamin K as menadione dimethylpyrimidinol bisulfite; 3.7 mg of riboflavin; 22 mg of niacin; 14.7 mg of pantothenic acid as D-calcium pantothenate; 16.5 μ g of vitamin B₁₂; 0.35 mg of iodine as ethylenediamine dihydroiodide; 0.25 mg of selenium as sodium selenite; 150 mg of zinc as zinc oxide; 150 mg of iron as ferrous sulfate; 9.9 mg of copper as copper sulfate; and 4.95 mg of manganese as manganese oxide.

recorded every 2 wk during the study to determine ADG, ADFI, and G:F. When the average BW of pigs in a pen reached 114 ± 2.25 kg, pigs were slaughtered, and tissue samples and carcass data were collected. On d 91 of the study, the first group of pigs reached the target BW and was marketed. At that time, growth performance and feed intake were determined for all pigs. Growth performance data were calculated for the period from d 0 to 91, and d 0 to marketing (overall) for each pen.

All pigs were kept on their respective diets until removed for market. On the day of marketing, pigs were weighed, tattooed individually with a unique number for each pig, and transported 3 km to a local assembly point. From this assembly point, pigs were transported about 350 km to a large commercial abattoir (Morrell Foods, Sioux Falls, SD). Pigs were slaughtered on the same day they were delivered to the abattoir. Of the 240 pigs that began the experiment, 225 were tattooed for collection of carcass data because 14 gilts were retained for breeding purposes and 1 pig died. At the time of slaughter, HCW was determined and 10th rib backfat thickness and loin depth were measured (Fat-O-Meater, SFK Technology, Copenhagen, Denmark) by plant personnel. Percent carcass lean was calculated using the following equation: $58.85 + [(-0.61 \times 10\text{th rib backfat depth, mm}) + (0.12 \times \text{loin depth, mm})]$. Useable

carcass composition data were collected from 188 pigs assigned to the growth performance study.

Pigs slaughtered on 2 marketing days and 1 wk apart were designated for meat quality assessments. These slaughter groups were established because 2 pens from each dietary treatment achieved the desired market weight and were marketed on the same day. Seventy-seven and 68 pigs were marketed in the first and second slaughter groups, respectively. Approximately 24 h postmortem, 111 bellies (average internal temperature of 6.7°C; 74 and 37 bellies from groups 1 and 2, respectively) from the left sides of the carcasses were retrieved and subjected to a firmness test. Bellies from 34 carcasses were not recovered. The firmness test consisted of measuring belly length on a flat surface and then placing it skin-side down on the sharp edge of a triangular stainless steel smoke stick. The distance between the 2 ends of the suspended belly was then measured.

Belly firmness score, which is equal to the upper angle of the isosceles triangle created by hanging the belly over the smoke stick, was calculated as $= \cos^{-1} \{ [0.5(L^2) - D^2] / [0.5(L^2)] \}$ for each retrieved belly. Belly thickness, not including the skin, was determined by inserting a probe at the scribe line midway between the cranial and caudal ends. A fat sample was collected midway between the cranial and caudal ends of the belly at a point just dorsal to the scribe line and were

Table 2. Composition of the experimental finisher diets (as-fed basis)

Item	Early finisher diet ¹				Middle finisher diet ²				Late finisher diet ³			
					DDGS ⁴ inclusion, %							
	0	10	20	30	0	10	20	30	0	10	20	30
Ingredient, %												
Corn	76.35	69.15	61.75	54.55	82.60	75.40	68.05	60.95	85.60	78.15	71.05	63.95
Soybean meal (46% CP)	18.00	15.75	13.75	11.50	13.25	11.00	9.00	6.75	10.25	8.25	6.00	3.75
Soybean oil	3.00	2.55	2.10	1.65	1.50	1.05	0.55	0.05	1.50	1.05	0.55	0.05
DDGS	0.00	10.00	20.00	30.00	0.00	10.00	20.00	30.00	0.00	10.00	20.00	30.00
Dicalcium phosphate	1.15	0.85	0.55	0.25	1.20	0.90	0.55	0.25	1.20	0.90	0.55	0.25
Limestone	0.80	1.00	1.15	1.35	0.75	0.95	1.15	1.30	0.75	0.95	1.15	1.30
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin trace mineral premix ⁵	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
L-Lysine·HCl	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Analyzed composition												
Ca, %	0.70	0.77	0.81	0.74	0.78	0.77	0.81	0.79	0.74	0.72	0.67	0.68
P, %	0.56	0.63	0.60	0.55	0.65	0.59	0.55	0.57	0.49	0.52	0.49	0.48
CP, %	13.3	15.2	16.5	17.4	12.6	13.3	14.7	15.6	12.3	12.7	13.1	14.0
Lys, %	0.82	0.86	0.88	0.84	0.72	0.73	0.75	0.70	0.64	0.62	0.62	0.57
Met and Cys, %	0.50	0.55	0.64	0.71	0.46	0.49	0.58	0.63	0.44	0.45	0.53	0.57
Thr, %	0.49	0.56	0.64	0.71	0.47	0.48	0.58	0.64	0.45	0.45	0.53	0.55
Trp, %	0.16	0.17	0.16	0.18	0.14	0.15	0.16	0.17	0.13	0.13	0.14	0.13

¹Diets were formulated to contain 3,412 kcal/kg of ME, 0.85% total Lys, 0.62% Ca, and 0.52% total P for pigs weighing 54 to 72 kg.

²Diets were formulated to contain 3,359 kcal/kg of ME, 0.72% total Lys, 0.60% Ca, and 0.51% total P for pigs weighing 72 to 91 kg.

³Diets were formulated to contain 3,364 kcal/kg of ME, 0.64% total Lys, 0.59% Ca, and 0.50% total P for pigs weighing 91 to 114 kg.

⁴Distillers dried grain with solubles.

⁵Vitamin-trace mineral premix that supplied the following nutrients per kilogram of feed: 3,667 IU of vitamin A as retinyl acetate; 616 IU of vitamin D₃; 15 IU of vitamin E as DL- α -tocopherol acetate; 2.4 mg of vitamin K as menadione dimethylpyrimidinol bisulfite; 3.7 mg of riboflavin; 22 mg of niacin; 14.7 mg of pantothenic acid as D-calcium pantothenate; 16.5 μ g of vitamin B₁₂; 0.35 mg of iodine as ethylenediamine dihydroiodide; 0.25 mg of selenium as sodium selenite; 150 mg of zinc as zinc oxide; 150 mg of iron as ferrous sulfate; 9.9 mg of copper as copper sulfate; and 4.95 mg of manganese as manganese oxide.

packaged and transported to the South Dakota State University Meat Laboratory. Fat samples were analyzed in duplicate for iodine absorption number by the Hanus method, using approximately 0.5 g of dissolved fat (AOAC, 1998).

Vacuum-packaged, boneless loin sections (n = 110) from the left sides of the carcasses in the 2 slaughter groups were purchased and transported to the South Dakota State University Meat Laboratory and stored (1°C) for 11 d. On d 12 postmortem, the loins were weighed, removed from the vacuum-packages, allowed to drip for approximately 15 min, and reweighed. From these data, purge loss was determined and expressed as a percentage of initial loin weight (NPPC, 2000). Loins were then cut in half, and ultimate pH of the LM in the caudal end of the cranial loin section was measured (Meatcheck 160 pH meter, Sigma Electronic GmbH, Erfurt, Germany).

From the cranial end of the caudal section of the loin, a chop (2.5-cm thick) designated for drip loss was removed and trimmed of all subcutaneous fat and extra muscles. The remaining loin section was frozen (-16°C) for subsequent Warner-Bratzler shear force measurement. Chops designated for drip loss were also assessed for color, marbling, and firmness according to NPPC (1999) standards. Additionally, L* color value was measured with a D65 illuminant on those chops used for drip loss determination (Minolta Chroma Meter CR-

310 colorimeter, Minolta Corp., Ramsey, NJ). Chops were then weighed, retail wrapped on styrofoam trays, and arranged at an approximate 30 degree angle. After 24 h, chops were reweighed and drip loss was determined and expressed as a percentage of initial weight (NPPC, 2000).

Two chops (2.5-cm thick) from each frozen loin section were cut with a bandsaw and placed in freezer storage (-16°C) for 1 to 2 wk. Chops were then thawed for 24 h at 1°C and cooked with an impingement oven (Model 1132-000-A, Lincoln Impinger, Fort Wayne, IN) at 190.5°C for 10.5 min. The resulting average final internal temperature of the chops was 68°C. Cooked chops were cooled to room temperature (20°C) before three 1.27-cm diam. cores per chop (6 cores per animal) were removed parallel to the longitudinal orientation of the muscle fibers. Individual cores were subjected to shear force determination using a Warner-Bratzler shear machine (G-R Manufacturing Co., Manhattan, KS). An average peak shear force was calculated and recorded for each pair of chops. Chops were weighed before and after cooking to determine cooking loss.

Statistical Analysis

Growth performance and carcass composition data were analyzed as a completely randomized design using PROC GLM (SAS Inst. Inc., Cary, NC). The statistical

Table 3. Least squares means for BW, ADG, ADFI, and G:F responses to dietary treatments

Item	DDGS ¹ inclusion, %				Pooled SE	P-value		
	0	10	20	30		Trt ²	Linear	Quadratic
No. of pigs	59	60	60	60	—	—	—	—
No. of pens	6	6	6	6	—	—	—	—
Initial BW, kg	28.5	28.5	28.1	28.2	0.4	0.76	0.36	0.91
CV, ³ %	8.28	8.98	8.48	9.75	1.05	0.76	0.48	0.79
D 0 to 91								
ADG, g	861 ^a	855 ^a	815 ^b	806 ^b	7	0.01	0.01	0.85
ADFI, g	2,285	2,275	2,206	2,251	39	0.51	0.29	0.50
G:F	0.38 ^a	0.38 ^a	0.37 ^a	0.36 ^b	0.004	0.05	0.01	0.26
D 91 BW, kg	105.9 ^a	106.4 ^a	102.3 ^b	101.5 ^b	0.8	0.01	0.01	0.46
CV, %	6.58 ^a	7.45 ^a	8.18 ^a	10.45 ^b	0.68	0.01	0.01	0.32
Overall								
ADG, g	862 ^a	859 ^a	827 ^{bc}	808 ^{bd}	6	0.01	0.01	0.24
ADFI, g	2,379	2,371	2,309	2,354	38	0.59	0.38	0.50
G:F	0.36 ^a	0.36 ^a	0.36 ^a	0.34 ^b	0.004	0.02	0.01	0.19
Final BW, kg	116.9 ^a	117.6 ^a	113.9 ^b	111.9 ^b	1.4	0.04	0.01	0.36
CV, %	6.92 ^a	7.15 ^a	8.30 ^{ac}	10.40 ^{bd}	0.74	0.02	0.01	0.23
No. of days	103.5	103.5	103.5	103.5	1.2	1.00	1.00	1.00

^{a,b}Means within row with unlike superscripts differ ($P < 0.05$).

^{c,d}Means within row with unlike superscripts differ ($P < 0.10$).

¹Distillers dried grain with solubles.

²Overall effect of dietary DDGS treatment.

³Within-pen CV.

model included dietary treatment (0, 10, 20, and 30% DDGS), initial weight group (light, medium, and heavy), and the interaction of diet and weight group. Mean separation was achieved using the PDIFFF option of SAS. In addition, orthogonal polynomials were used to determine linear and quadratic effects of DDGS concentrations. The pen served as the experimental unit in the analyses.

Meat quality traits of loins and bellies were analyzed as a completely randomized design using PROC GLM. The statistical model included dietary treatment (0, 10, 20, and 30% DDGS), sex of the pig, and 2 slaughter groups. Analysis of belly firmness score included belly thickness as a linear covariate. Means were separated using the PDIFFF option of SAS. Orthogonal polynomials were used to determine linear and quadratic effects of dietary DDGS concentrations. Additionally, regressions of iodine number on belly firmness score, belly thickness on belly firmness score, and iodine number and belly thickness on belly firmness score were developed. Pig served as the experimental unit for meat quality analysis. All means are reported as least squares means. Treatment effects were considered significant at $P < 0.05$, whereas $P < 0.10$ was considered a statistically significant trend.

RESULTS AND DISCUSSION

Growth Performance

Dietary treatment and initial weight groups did not interact for any response variables. Our primary interest was the effect of dietary DDGS. Consequently, only the main effects of dietary treatment are presented.

Least squares means for BW and growth performance responses are presented in Table 3. Initial BW and variation in BW were similar across dietary treatment groups. Including 20 or 30% DDGS in the diet resulted in similar feed intakes compared with the 0 or 10% dietary concentration, but lower growth rate (815 and 806 vs. 861 and 855 g/d, respectively; $P < 0.05$) over the initial 91-d feeding period. This resulted in poorer G:F for pigs fed the 30% DDGS diets compared with pigs fed 0 or 10% DDGS diets ($P < 0.05$). Similar trends were observed over the entire feeding period. Final weight was greater ($P < 0.05$) for pigs fed the 0 and 10% DDGS diets (116.9 and 117.6 kg, respectively) compared with pigs fed 20 or 30% DDGS (113.9 and 111.9 kg, respectively), although the experiment was designed to minimize differences in final BW.

These results indicate that grower-finisher pigs will readily consume diets containing up to 30% high-quality DDGS. Therefore, high-quality DDGS seems to be an acceptable substitute for corn and soybean meal in a grower-finisher diet without negatively affecting voluntary food intake. However, when diets are formulated on a total AA basis, concentrations of high-quality DDGS at 20% or greater results in poorer growth rate and efficiency of BW gain. This is not surprising considering that high-quality DDGS is high in CP and many essential AA (Spiehs et al., 2002) but relatively low in Lys similar to its base grain, corn. Whereas the apparent AA digestibility coefficients of high-quality DDGS are greater (Whitney et al., 2000) than previous published estimates (NRC, 1998), they are still less than soybean meal, which DDGS partially replaces in a corn-soybean meal diet formulated on a total AA basis. Therefore, a combination of inadequate supplies of

Table 4. Least squares means for carcass responses to dietary treatments

Item	DDGS ¹ inclusion, %				Pooled SE	P-value		
	0	10	20	30		Trt ²	Linear	Quadratic
No. of pens	6	6	6	6	—	—	—	—
No. of pigs	45	45	48	50	—	—	—	—
No. of barrows	24	26	29	27	—	—	—	—
No. of gilts	21	19	19	23	—	—	—	—
Slaughter wt, kg	116.8 ^a	119.2 ^{ac}	113.1 ^b	112.1 ^d	2.0	0.09	0.03	0.42
HCW, kg	85.7 ^c	86.8 ^c	81.5 ^d	80.6 ^d	1.4	0.02	0.01	0.50
Dressing, %	73.35 ^c	72.80 ^c	72.07 ^d	71.90 ^d	0.29	0.01	0.01	0.53
Backfat depth, mm	21.3	21.8	21.1	20.6	0.7	0.68	0.35	0.49
Loin depth, mm	56.5 ^{ac}	53.9 ^b	54.8 ^c	51.6 ^d	0.9	0.02	0.02	0.80
Lean, %	52.6	52.0	52.6	52.5	0.5	0.80	0.85	0.56

^{a,b}Means within row with unlike superscripts differ ($P < 0.10$).

^{c,d}Means within row with unlike superscripts differ ($P < 0.05$).

¹Distillers dried grain with solubles.

²Overall effect of dietary DDGS treatment.

available Lys and other AA, in association with increased energy utilization to deaminate and excrete excess AA, likely elicited the decreased growth performance and poorer efficiency of gain when diets are formulated on a total AA basis and contain 20% or more high-quality DDGS.

Carcass Composition

Least squares means for initial carcass weight and composition are presented in Table 4. Slaughter weights tended to be greater for pigs fed the 0 and 10% DDGS treatments (116.8 and 119.2 kg) compared with pigs fed the 20 or 30% DDGS diets (113.1 and 112.1 kg; $P < 0.10$). This resulted in greater HCW for pigs fed 0 or 10 compared with 20 or 30% DDGS diets ($P < 0.05$). As DDGS concentration increased in the diet, carcass weight linearly decreased ($P < 0.01$).

Backfat depth was largely unaffected by dietary treatment. Similarly, percent carcass lean was unaffected by dietary treatment. Increasing dietary DDGS concentration decreased loin depth linearly ($P < 0.05$). Pigs fed the 0% DDGS diets had greater loin depths compared with pigs fed the 30% DDGS diets ($P < 0.05$), with intermediate loin depths from pigs fed 10 or 20%

DDGS. The differences in loin depth certainly were influenced by the differences in slaughter weight of pigs assigned to the 4 dietary treatments. These results indicate that, although growth performance was negatively affected by increased dietary DDGS, carcass composition was largely unaffected as indicated by the similar fat depths and percent carcass lean across dietary treatments.

Fat and Muscle Quality

Iodine number increased linearly ($P < 0.05$), and thus belly fat became more unsaturated, as the dietary concentration of DDGS increased (Table 5). Researchers have clearly established that feeding diets containing an unsaturated fat source can alter the degree of saturation in pork fat. Lea et al. (1970) characterized adequately firm pork fat sampled from above the tailhead or around the kidneys as having an iodine number below 70. In our study, iodine values were greater than 70 for diets containing 20 and 30% DDGS. Overall, our values were within the upper range (50 to 72) of iodine numbers reported for pork belly fat in swine fed up to 19% raw soybeans (Pontif et al., 1987) or barley- and maize-based diets (Lucas et al., 1960; Lawrence, 1974).

Table 5. Fat quality characteristics of pigs fed differing concentrations of distillers dried grain with solubles (DDGS)

Item	DDGS inclusion, %				Pooled SE	P-value		
	0	10	20	30		Trt ¹	Linear	Quadratic
No. of bellies	28	27	23	33	—	—	—	—
Belly thickness, cm	3.15 ^a	3.00 ^{ab}	2.84 ^{bc}	2.71 ^c	0.11	0.02	0.01	0.92
Belly firmness score, ² degrees	27.3 ^a	24.4 ^a	25.1 ^a	21.3 ^b	1.2	0.01	0.01	0.73
Adjusted belly firmness score, ³ degrees	25.9 ^d	23.8 ^{de}	25.4 ^d	22.4 ^e	1.0	0.07	0.11	0.66
Iodine number	66.8 ^d	68.6 ^e	70.6 ^f	72.0 ^f	0.7	0.01	0.01	0.74

^{a-c}Means within a row with different superscripts differ ($P < 0.10$).

^{d-f}Means within a row with different superscripts differ ($P < 0.05$).

¹Overall effect of dietary DDGS treatment.

²Belly firmness score = $\cos^{-1}\{[0.5(L_2) - D_2]/[0.5(L_2)]\}$, where L = belly length measured on a flat surface and D = the distance between the 2 ends of a suspended belly; greater belly firmness scores indicate firmer bellies.

³Belly firmness score adjusted for belly thickness.

Table 6. Muscle quality characteristics of pigs fed differing concentrations of distillers dried grain with solubles (DDGS)

Trait	DDGS inclusion, %				Pooled SE	P-value		
	0	10	20	30		Trt ¹	Linear	Quadratic
No. of observations	28	27	22	33	—	—	—	—
L* ²	54.3	55.1	55.8	55.5	0.6	0.24	0.06	0.32
Color score ³	3.17	3.15	3.05	3.12	0.16	0.95	0.67	0.79
Firmness score ⁴	2.21	2.04	2.06	2.08	0.10	0.65	0.43	0.37
Marbling score ⁵	1.89	1.85	1.72	1.91	0.12	0.71	0.78	0.33
Ultimate pH	5.61	5.56	5.60	5.61	0.03	0.70	0.79	0.44
11-d purge loss, %	2.06 ^a	2.37	2.84 ^b	2.54	0.22	0.12	0.04	0.19
24-h drip loss, %	0.70	0.67	0.71	0.74	0.03	0.49	0.22	0.43
Cooking loss, %	18.7	18.5	18.3	18.8	0.5	0.91	0.99	0.51
Total moisture loss, ⁶ %	21.4	21.5	21.8	22.0	0.6	0.86	0.40	0.92
Warner-Bratzler shear force, kg	3.40	3.44	3.33	3.30	0.10	0.74	0.33	0.71

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹Overall effect of dietary DDGS treatment.

²0 = black to 100 = white.

³1 = pale pinkish gray to white; 2 = grayish pink; 3 = reddish pink; 4 = dark reddish pink; 5 = purplish red; 6 = dark purplish red (NPPC, 1999).

⁴1 = soft; 2 = firm; 3 = very firm (NPPC, 1999).

⁵Visual scale, which approximates the percentage of intramuscular fat content (NPPC, 1999).

⁶Total moisture loss = 11-d purge loss + 24-h drip loss + cooking loss.

In the current study, a significant amount of unsaturated fatty acids was supplied to experimental diets from supplemental soybean oil in addition to the corn oil present in DDGS. We estimate, based on NRC (1998), that a typical swine finisher diet without supplemental fat (85% corn, 11% soybean meal) would contain about 3% unsaturated fatty acids. By comparison, we estimated our phase 5 control diet contained 4.33% unsaturated fatty acids and the phase 5 diet with 30% DDGS contained 4.96% unsaturated fatty acids. We expect that if an animal fat source, which is lower in unsaturated fatty acid concentration, were added to the diets, or no supplemental fat was added, the iodine values of carcass fat from pigs fed high concentrations of DDGS would be lower, and the negative effects of adding DDGS to the diets on pork fat quality would be less. The effect of DDGS feeding on iodine number was reflected in the analysis of belly firmness score. Lower adjusted belly firmness scores ($P < 0.05$) indicated that bellies from pigs that were fed 30% DDGS were softer than bellies from pigs fed 0 or 20% DDGS. Softer bellies were most likely a consequence of elevated concentrations of dietary unsaturated lipids supplied by soybean oil and DDGS.

Based on curvilinear regression analysis, iodine number and belly thickness explained 14 and 33% of the observed variation in belly firmness score, respectively, and together iodine number and belly thickness explained 37% of the observed variation in belly firmness score (data not shown). Thus, degree of carcass fatness had a larger effect on belly firmness than did fat composition.

Color measurements (L*) of muscle were not different among dietary treatments (Table 6). Likewise, visual evaluations of the LM muscle did not differ among treatments for color, firmness, or marbling scores.

Moreover, ultimate pH was not different among treatments. Water holding capacity traits, including 24-h drip loss, cooking loss, and total moisture loss, were not influenced by feeding DDGS. Feeding the 20% DDGS diets increased ($P < 0.05$) 11-d purge loss compared with pigs fed diets containing 0% DDGS. Dietary treatment did not affect Warner-Bratzler shear force values of cooked loin chops. These data indicate feeding DDGS in swine finishing diets did not have meaningful effects on pork muscle quality.

IMPLICATIONS

Corn distillers dried grains with solubles originating from modern ethanol plants located in the upper Midwestern region of the United States are an abundant feed ingredient. Including 10% distillers dried grain with solubles in conventional swine grower-finisher diets has no detrimental effects on pig performance, carcass quality, or pork quality. When diets are formulated on a total AA basis, it seems that inclusion rates of 20% or higher result in decreased growth performance. Including distillers dried grain with solubles at concentrations up to 30% in a diet with supplemental soybean oil for grower-finisher pigs does not seem to affect muscle composition or quality but is likely to decrease the saturation of fatty acids, resulting in softer bellies, and may negatively affect further processing traits.

LITERATURE CITED

- AOAC. 1998. Official Methods of Analysis. 16th ed. Assoc. Off. Anal. Chem., Gaithersburg, MD.
- Cromwell, G. L., T. S. Stahly, and H. J. Monegue. 1984. Distillers dried grains with solubles for growing-finishing swine. Pages 15–16 in Swine Res. Rep. No. 284, Kentucky Agric. Exp. Sta., Lexington.

- Cromwell, G. L., T. S. Stahly, H. J. Monegue, and J. R. Overfield. 1983. Distillers dried grains with solubles for growing-finishing swine. Pages 30–32 in Swine Res. Rep. No. 274, Kentucky Agric. Exp. Sta., Lexington.
- Harmon, B. G. 1975. The use of distillers dried grains with solubles as a source of lysine for swine. Proc. 30th Distillers Feed Conf. 30:23–28.
- Harper, A., and D. Forsyth. 1998. Relative value of feedstuffs for swine. In Pork Industry Handbook - 112. Iowa State Univ. Extension, Ames.
- Lawrence, T. L. J. 1974. Short note: The effect on bacon pig backfat iodine number and caloric value of feeding barley or maize based diets to give different growth rates. J. Agric. Sci. Camb. 82:177–179.
- Lea, C. H., P. A. T. Swoboda, and D. P. Gatherum. 1970. A chemical study of soft fat in cross-bred pigs. J. Agric. Sci. Camb. 74:1–11.
- Lucas, I. A. M., I. McDonald, and A. F. C. Calder. 1960. Some further observations upon the effects of varying the plane of feeding for pigs between weaning and bacon weight. J. Agric. Sci. Camb. 54:81–99.
- NPPC. 1999. Pork Quality Standards. Natl. Pork Producers Council, Des Moines, IA.
- NPPC. 2000. Pork Composition and Quality Assessment Procedures. Natl. Pork Producers Council, Des Moines, IA.
- NRC. 1982. United States-Canadian Tables of Feed Composition. 3rd rev. Natl. Acad. Press, Washington, DC.
- NRC. 1998. Nutrient Requirements of Swine. 10th ed. Natl. Acad. Press, Washington, DC.
- Pontif, J. E., L. L. Southern, D. F. Coombs, K. W. McMillin, T. D. Bidner, and K. L. Watkins. 1987. Gain, feed efficiency, and carcass quality of finishing swine fed raw soybeans. J. Anim. Sci. 64:177–181.
- Spiehs, M. J., M. H. Whitney, and G. C. Shurson. 2002. Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 80:2639–2645.
- Wahlstrom, R. C., and C. German. 1968. A study of distillers by-products in growing-finishing swine rations. Pages 1–5 in Anim. Sci. Series No. 68-27, South Dakota Agric. Exp. Sta., Brookings.
- Wahlstrom, R. C., and G. W. Libal. 1969. A study of lysine and distillers dried grains with solubles in growing-finishing swine rations. Pages 1–3 in Anim. Sci. Series No. 69-35, South Dakota Agric. Exp. Sta., Brookings.
- Weigel, J. C., D. Loy, and L. Kilmer. 1997. Feed Co-Products of the Dry Corn Milling Process. Renewable Fuels Assoc. and Natl. Corn Growers Assoc., Washington, DC and St. Louis, MO.
- Whitney, M. H., and G. C. Shurson. 2001. Availability of phosphorus in distiller's dried grains with solubles for growing swine. J. Anim. Sci. 79(Suppl. 1):108. (Abstr.)
- Whitney, M. H., M. J. Spiehs, G. C. Shurson, and S. K. Baidoo. 2000. Apparent ileal amino acid digestibilities of corn distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 78(Suppl. 1):185. (Abstr.)