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Corn distillers dried grains with solubles in diets for growing-finishing pigs: A cooperative study[1,2]

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North Central Coordinating Committee on Swine Nutrition[4,5,6]

ABSTRACT: An experiment involving 560 crossbred pigs (28 replications of 4 to 6 pigs per pen) was conducted at 9 research stations to assess the effects of dietary concentrations of corn distillers dried grains with solubles (DDGS) on pig performance and belly firmness. Fortified corn-soybean meal diets containing 0, 15, 30, or 45% DDGS were fed in 3 phases from 33 to 121 kg of BW. A common source of DDGS containing 90.1% DM, 26.3% CP, 0.96% Lys, 0.18% Trp, 9.4% crude fat, 34.6% NDF, 0.03% Ca, and 0.86% P was used at each station. Diets were formulated to contain 0.83, 0.70, and 0.58% standardized ileal digestible (SID) Lys during the 3 phases with diets changed at 60 and 91 kg of BW, respectively. The DDGS replaced corn and soybean meal, and up to 0.172% Lys and 0.041% Trp were added to maintain constant SID concentrations of Lys and Trp in each phase. At each station, 2 pigs from each pen in 2 replications were killed and a midline backfat core was obtained for fatty acid analysis and iodine value. In most instances, there were differences among stations ($P < 0.01$), but the station × treatment interactions were few. Body weight gain was linearly reduced in pigs fed the greater amounts of DDGS (0 to 45%) during phase I (950, 964, 921, and 920 g/d; $P < 0.01$) and over the entire experimental period (944, 953, 924, and 915 g/d; $P = 0.03$), but ADFI (2.73, 2.76, 2.68, and 2.70 kg) and G:F (347, 347, 345, and 341 g/kg) were not affected ($P = 0.15$ and $P = 0.33$, respectively) during the entire test. Backfat depth was reduced (linear, $P < 0.02$) by increasing amounts of DDGS (22.5, 22.7, 21.4, and 21.6 mm), but LM area (47.4, 47.4, 46.1, and 45.4 cm^2) was not affected ($P = 0.16$) by treatments. Estimated carcass fat-free lean was 51.9, 52.2, 52.4, and 52.1% for 0 to 45% DDGS, respectively (linear, $P = 0.06$). Flex measures obtained at 6 stations indicated less firm bellies as dietary DDGS increased (lateral flex: 11.9, 8.6, 8.4, and 6.6 cm; linear, $P < 0.001$; vertical flex: 26.1, 27.4, 28.2, and 28.7 cm; linear, $P < 0.003$). Saturated and monounsaturated fatty acid concentrations in subcutaneous fat decreased linearly ($P < 0.001$) and PUFA concentrations increased linearly ($P < 0.001$) with increasing DDGS in the diet. Iodine values in inner (61.1, 68.2, 74.7, and 82.2) and outer (67.9, 73.6, 79.6, and 85.8) backfat increased linearly ($P < 0.001$) as DDGS in the diet increased. In this study, feeding diets with 30 or 45% DDGS did not have major effects on growth performance, but resulted in softer bellies. Regression analysis indicated that iodine values increased 4.3 units for every 10 percentage unit inclusion of DDGS in the diet.

Key words: belly firmness, carcass, distillers grain, fatty acid, iodine value, pig

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INTRODUCTION

Numerous ethanol plants have been built over the past several years. The demand for corn as a resource for ethanol production has contributed to a marked increase in corn prices, causing greater feed costs and reduced profits for swine producers. Expanded ethanol production has resulted in large amounts of distillers dried grains with solubles (**DDGS**) being produced.

Stein (2007) reviewed the literature on the feeding of DDGS for swine and found that the data were inconsistent with respect to the maximum amount of DDGS that can be included in diets without negatively affecting growth performance or carcass firmness. His conclusions were that up to 20% DDGS could be used in finishing diets, even though some producers were using inclusion rates of up to 35% without compromising growth and carcass traits.

Some of the confusion regarding the effects of dietary DDGS concentrations on swine growth and carcass firmness is likely due to variation in source of DDGS, method of diet formulation, and other factors. Sometimes, conclusions were derived from experiments that were too small with inadequate numbers of replications per treatment. Experiments with large numbers of replications can be achieved by collaborative research, in which several research stations follow a common protocol and the data are pooled and analyzed. A collaborative study involving several research stations with large numbers of replications may give the industry a better understanding of the amount of DDGS that can be used in swine diets without decreasing growth performance or causing excessively soft carcass fat.

The objective of this collaborative study conducted by several research stations was to evaluate moderate to high amounts of DDGS in growing-finishing swine diets. Specifically, we wanted to determine if up to 30 or 45% DDGS can be incorporated into corn-soybean meal diets that were formulated on the basis of standardized ileal digestible (**SID**) AA without decreasing growth performance or negatively affecting carcass quality and belly firmness of swine.

MATERIALS AND METHODS

A collaborative study involving 560 crossbred pigs was conducted at 9 research stations. All participants were members of a North Central Coordinating Committee called the NCCC-42 (formerly NCR-42) Committee on Swine Nutrition. A common protocol was followed at each participating station, and experiments were conducted in accordance with animal care guidelines at each station.

To participate, each station was required to collect and contribute data from a minimum of 2 replications with a minimum of 4 pigs per pen for each of 4 treatment groups. Growing-finishing pigs were fed diets from 33 to 121 kg of BW in 3 phases. A total of 28 replications (17 replications of barrows and 11 replications of gilts) of 4 to 6 pigs per pen were included in the study. Table 1 shows the 9 stations that participated, the number of replications per station, the number of pigs per pen, and the total number of pigs in the study. The initial and final BW of the pigs at each station are also shown in Table 1.

DDGS

The study was designed to evaluate 4 dietary treatments consisting of a corn-soybean meal diet and 3 additional diets containing 15, 30, or 45% DDGS. A common source of DDGS (Table 2) from a single plant (Adkins Energy, LLC, Lena, IL) was provided for the study by a commercial company (ADM Alliance Nutrition, Decatur, IL). Two semi-truck loads of DDGS were obtained from the plant on the same day. Samples of DDGS were taken from each truck for later analysis. The DDGS was taken to a commercial mill (ADM Alliance Nutrition, Lincoln, IL), bagged, and shipped to the participating stations. The DDGS arrived at the participating stations in October, 2007, and diets were mixed and experiments initiated within 1 to 4 mo after receiving the DDGS.

Diets

The same diet formulations (Table 3) were used by all participants. Diets for 3 phases were formulated on the basis of SID AA [SID AA is considered to be the same as true ileal digestible AA, which is listed by the NRC (1998)] using analyzed values of total AA for DDGS and calculated values of AA for corn and soybean meal (NRC, 1998). The SID AA values for DDGS were based on estimates of Stein (2007), and those for corn and soybean meal were based on true ileal digestible coefficients listed in NRC (1998). Diets were calculated to contain 0.83, 0.70, and 0.58% SID Lys during the 3 phases. Diet changes occurred at 60 and 91 kg of BW, respectively. The DDGS was substituted for corn and soybean meal. Additions of L-Lys·HCl and L-Trp to diets containing DDGS were made to maintain constant SID concentrations of Lys and Trp in each phase. The Ca and digestible P concentrations were constant among diets during each phase. Because of the increased concentration of digestible P in DDGS, supplemental P was not included in the diets containing the 45% DDGS. All diets were fortified with salt, vitamins, and trace minerals to meet or exceed NRC (1998) requirements, and Tylosin (Elanco Animal Health, Greenfield, IN) was included in all diets.

Each participating station mixed their diets using their own corn, soybean meal, and other ingredients (except for DDGS). Diets at each station were sampled and a composite of each diet for each phase (n = 12) was sent to the study coordinator. Each diet (n = 108) was analyzed for CP and crude fat at the University of Kentucky and for fatty acid composition at the University of Georgia.

Table 1. Participating stations and their contributions to the study

Research station	No. of replications[1]	No. of pigs per pen	Total No. of pigs	Avg initial BW, kg	Avg final BW, kg
University of Kentucky	3	5	60	34	120
University of Minnesota	4	5	80	27	119
University of Missouri	4	4	64	31	120
University of Nebraska	3	6	72	34	120
North Carolina State University	2	5	40	34	116
The Ohio State University	2	6	48	33	125
Oklahoma State University	3	4 or 6	68	32	125
Purdue University	4	5	80	35	120
University of Wisconsin	3	4	48	34	120
Total	28	—	560	—	—

[1]Three replications of barrows at Nebraska, 1 replication of barrows at North Carolina and Wisconsin, and 2 replications of barrows at the other stations (n = 17). The additional replications in the experiment (n = 11) were gilts.

Allotment and Management of Pigs

At each station, pigs were randomly allotted to treatments on the basis of BW, sex, and ancestry. Barrows and gilts were penned separately at each station. Pigs were weighed and feed disappearance was determined at the end of each phase. Diets and water were provided on an ad libitum basis, and diets were fed in meal form. The growth performance aspect of the experiment was summarized on a replication basis when the pigs in the control pen (diet 1) of a given replication reached an average BW of 120 kg. At most stations, any pens within a replication that did not reach the targeted BW were continued on their respective diets until the mean BW of pigs in the pen reached 120 kg. This procedure allowed ADG, ADFI, and G:F to be summarized on a constant-time basis and the carcass data on a constant-weight basis.

At the end of the experiment, 2 pigs from each pen that were closest to the pen mean weight were killed and HCW was determined. After a 24-h chill at 4°C, 10th-rib backfat and 10th-rib LM area were measured and carcass fat-free lean was estimated using the NPPC (2000) equation. A sample of backfat at the 10th rib was collected for determination of fatty acid profile and iodine value (a measure of carcass firmness). Samples were packed in dry ice and sent to the University of Georgia (M. J. Azain) for the determination of the fatty acid profiles of the inner and outer portions of the subcutaneous backfat.

Table 2. Analyzed composition of the distillers dried grains with solubles (DDGS) used in the study (as-fed basis)

Item	Composition
DM, %	90.1
CP, %	26.3
Crude fat, %	9.4
ADF, %	14.0
NDF, %	34.6
Crude fiber, %	6.5
Ash, %	5.1
Ca, %	0.03
P, %	0.86
K, %	0.95
Mg, %	0.30
Na, %	0.20
S, %	0.68
Cu, mg/kg	5
Fe, mg/kg	63
Mn, mg/kg	13
Zn, mg/kg	63
Lys, %	0.96
Trp, %	0.18
Thr, %	0.99
Met, %	0.51
Cys, %	0.50
Ile, %	1.02
Val, %	1.35
Linoleic acid, % of total fatty acids	57.3
Iodine value	124.4

Belly Flex

Six stations determined belly firmness using an objective flex test developed by Rentfrow et al. (2003). Each station constructed an apparatus similar to the one shown in Figure 1 to determine belly flex. Bellies were removed from the right side of the chilled carcass and fabricated to comply with Institutional Meat Purchasing Specifications as described by the North American Meat Processors Association (2010). The spareribs and related cartilage were removed, bellies were squared (approximately 35 × 48 cm), and all remaining leaf fat was removed. The chilled, fresh bellies with the skin on were then centered, fat side down, on a 7.5-cm diameter polyvinyl chloride pipe mounted perpendicular to a board marked with a 2.54-cm grid matrix. Lateral and vertical flexes were determined from the degree of belly flex relative to the grid matrix. A vertical belly flex of zero meant the belly was parallel to the floor and completely stiff. A lateral belly flex of 10 cm meant that the belly flexed to a point where there was 10 cm between the end of the squared belly and a vertical line directly below the center of the supporting polyvinyl chloride pipe. The cranial and caudal halves of each belly were measured and the results of the 2 halves were averaged. A lower lateral and a higher vertical flex indicated a

Table 3. Composition of diets of pigs fed distillers dried grains with solubles (DDGS; as-fed basis)

	Phase I DDGS, %				Phase II DDGS, %				Phase III DDGS, %			
Item	0	15	30	45	0	15	30	45	0	15	30	45
Ingredient, %												
Corn	72.48	61.942	51.405	40.867	77.905	67.558	57.211	46.864	82.705	72.098	61.501	50.894
Soybean meal, dehulled	25.20	20.80	16.40	12.00	19.80	15.20	10.60	6.00	15.00	10.67	6.33	2.00
DDGS	—	15	30	45	—	15	30	45	—	15	30	45
L-Lys·HCl	—	0.067	0.133	0.200	—	0.073	0.147	0.220	—	0.065	0.130	0.195
L-Trp	—	0.011	0.022	0.033	—	0.014	0.027	0.041	—	0.012	0.024	0.036
Dicalcium phosphate	1.24	0.83	0.41	—	1.24	0.83	0.41	—	1.24	0.83	0.41	—
Ground limestone	0.58	0.85	1.13	1.40	0.58	0.85	1.13	1.400	0.58	0.85	1.13	1.40
Salt	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Vitamins-trace minerals[1]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Tylan-40[2]	0.05	0.05	0.05	0.05	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Calculated analysis												
CP, %	18.0	19.0	20.0	20.9	15.9	16.8	17.7	18.6	14.0	15.0	16.0	17.0
Total Lys, %	0.95	0.98	1.02	1.06	0.80	0.84	0.87	0.91	0.67	0.70	0.74	0.78
SID Lys,[3] %	0.83	0.83	0.83	0.83	0.70	0.70	0.70	0.70	0.58	0.58	0.58	0.58
SID Trp, %	0.18	0.18	0.18	0.18	0.16	0.16	0.16	0.16	0.13	0.13	0.13	0.13
Fat, %	3.6	4.5	5.4	6.3	3.6	4.6	5.5	6.4	3.7	4.6	5.5	6.4
NDF, %	9.2	13.0	16.8	20.6	9.2	13.0	16.8	20.6	9.3	13.1	16.9	20.6
Ca, %	0.60	0.60	0.60	0.60	0.58	0.58	0.58	0.58	0.57	0.57	0.57	0.57
Total P, %	0.61	0.6	0.59	0.58	0.58	0.58	0.57	0.56	0.56	0.56	0.55	0.54
Digestible P, %	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.25
ME, Mcal/kg	3.33	3.33	3.34	3.34	3.33	3.34	3.34	3.34	3.34	3.34	3.34	3.35
Analyzed												
CP, %	17.5	19.5	20.3	21.5	15.9	17.3	18.7	19.0	14.2	15.2	16.6	17.4
Fat, %	2.4	3.5	4.6	5.6	2.3	3.5	4.5	5.5	2.6	3.4	4.4	5.5
Linoleic acid, % of total	56.8	57.5	58.6	58.6	55.7	56.5	58.0	58.6	56.1	58.5	57.6	58.6
Iodine value	124.6	125.1	126.1	126.1	123.3	123.4	125.4	126.3	123.4	125.8	125.0	126.1

[1]The amounts of vitamin and trace mineral premixes added at the various stations were different, but sufficient amounts were included to meet or exceed NRC (1998) requirements for essential vitamins and trace minerals.

[2]Elanco Animal Health, Greenfield, IN. These concentrations of Tylan-40 provided 44 and 22 mg of tylosin per kilogram for phase 1 and phase II and III diets, respectively.

[3]The standardized ileal digestible (SID) Lys requirement (equivalent to the true ileal digestible Lys requirement; NRC, 1998) for pigs at the midpoint of the 3 phases is 0.80, 0.67, and 0.53%, respectively.

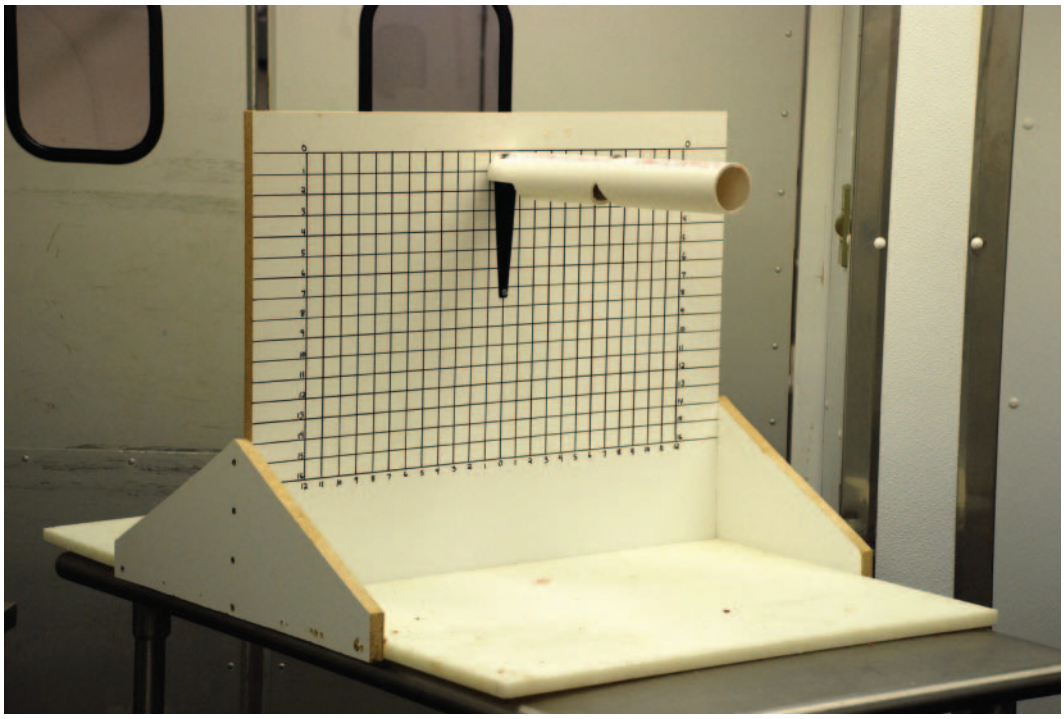

Figure 1. Apparatus that was fabricated by each station to quantify belly flex measurements. The numbers on the vertical and horizontal scales represent units of 2.54 cm. Color version available in the online PDF.

softer, more flexible belly. The belly flex measurements were determined in a room maintained at 7°C.

Chemical Analyses

The DDGS was analyzed in duplicate by a commercial laboratory (ADM Nutrition Laboratory, Decatur, IL) for DM (935.29), CP (990.03), crude fat (920.39), ash (942.05), and minerals (985.01) using AOAC (2005) procedures, and also for ADF, NDF, and crude fiber (Ankom Technology, Macedon, NY). The AA in DDGS were analyzed in quadruplicate by the University of Missouri Experiment Station Chemical Laboratory, Columbia, using ion exchange chromatography after acid hydrolysis with 6 *N* HCl for 24 h at 110°C (AOAC, 2005). Methionine and cysteine were oxidized to methionine sulfone and cysteic acid by treatment with performic acid before hydrolysis. Tryptophan was analyzed after alkaline hydrolysis. Diets for each phase at each station were analyzed in duplicate for CP (990.03) and crude fat (920.39) at the University of Kentucky using standard analytical procedures (AOAC, 2005).

The fatty acid profiles of the subcutaneous adipose tissue, diets, and DDGS were determined by gas chromatography (model 14 A, Shimadzu, Tokyo, Japan) with a flame ionization detector. Adipose tissue samples (50 to 100 mg) were transmethylated according to the method of Park and Goins (1994). Two milligrams of heptadecanoic acid (C 17:0) was added as an internal standard before processing. Fatty acid methyl esters in hexane were separated on a Supelcowax-10 fused capillary column (60 m × 0.53 mm, 0.5-mm film thickness; Supelco, Bellefonte, PA) under isothermal conditions. Column temperature was 220°C, injector temperature was 250°C, and detector temperature was 260°C. Injection volume was 0.5 uL, and helium was the carrier gas. Peak identification was based on known standards (Nu-Chek Prep, Elysian, MN). Iodine value was calculated according to AOCS (1998) using the following equation: iodine value = (C16:1 × 0.95) + (C18:1 × 0.86) + (C18:2 × 1.732) + (C18:3 × 2.616) + (C20:1 × 0.785) + (C22:1 × 0.723). The iodine value of the DDGS was determined from the fatty acid composition of the DDGS using the same equation.

Statistical Analysis

All performance and carcass data were collected at the participating stations using standardized forms and sent to the study coordinator for summarization and statistical analysis using the GLM procedure (SAS Inst. Inc., Cary, NC). The pooled data were analyzed as a split-plot design with station as the main plot and treatment as the subplot (Steel et al., 1997). Station effects were tested with replication within station as the main plot error. Treatment effects and the station × treatment interaction were tested with the replication within station × treatment as the subplot error. Pen was considered the experimental unit in all of the statistical analyses. Treatment responses were partitioned into linear, quadratic, and cubic trends using orthogonal polynomial contrasts. Unless stated otherwise, an α level of 0.05 was considered statistically significant.

RESULTS

The moderate to light color, pleasant odor, and analytical composition of the DDGS used in the study were indicative of a good-quality product. The CP and crude fat contents of the DDGS used in the study were slightly greater than listed in NRC (1998; 26.3 vs. 24.8% and 9.4 vs. 8.4%, respectively; Table 2), and the ADF was slightly less (14.0 vs. 16.3%) than listed in NRC (1998). The Lys percentage in the DDGS was considerably greater than that listed in NRC (1998; 0.96 vs. 0.62%), but Trp was less (0.18 vs. 0.25%). The concentrations of Thr, Met, Cys, Ile, and Val in the DDGS were similar to those listed by NRC (1998).

Several of the minerals in the DDGS differed substantially from those listed by NRC (1998). For example, the Ca concentration in the DDGS used in this study was considerably less than that listed by NRC (0.03 vs. 0.20%), as were Cu (5 vs. 57 mg/kg) and Fe (63 vs. 257 mg/kg), and to a lesser extent, Mn (13 vs. 24 mg/kg) and Zn (63 vs. 80 mg/kg). In contrast, the S content of the DDGS in our study was more than 2-fold greater than the content listed by NRC (1998) for DDGS (0.68 vs. 0.30%). The major fatty acid in the DDGS, as expected, was linoleic acid, which represented 57.3% of the total fatty acids. The iodine value of the DDGS was 124.4.

Analysis of the diets from each station indicated that the mean CP for the 4 diets during each phase was similar to calculated values (Table 3). The analyzed crude fat in the diets was approximately 1 percentage point less than the calculated values for the diets, but the increase in analyzed fat with incremental additions of DDGS was approximately the same as the increases in calculated fat. Percentages of linoleic acid in the diets ranged from 55.7 to 58.6, which was similar to the linoleic acid content (57.3%) of the DDGS. Similarly, iodine values of the diets (123.3 to 126.3) were about the same as the iodine value (124.4) of the DDGS.

As expected, there were large and statistically significant ($P < 0.001$) differences among stations in the growth performance and carcass traits, but in most instances (all except backfat, LM area, and estimated carcass lean percentage) the station × treatment interactions were not significant. In instances where the station × treatment interaction was significant, the interaction resulted from a difference in magnitude, and not the direction, of the response. Therefore, only the treatment means averaged across stations are reported.

Growth rate during the early portion of the study was reduced in pigs fed the 2 greater amounts of DDGS, resulting in a linear ($P < 0.01$) response during phase I (Table 4). This trend, though not statistically significant, continued throughout the study. Over the entire experimental period, there was a linear reduction ($P < 0.03$) in ADG with increasing amounts of DDGS in the diet. Inclusion of DDGS had little effect of ADFI except for a slight reduction at the 2 greater amounts of DDGS inclusion during phase I (cubic, $P < 0.05$) and over the entire test period (cubic, $P < 0.05$). Gain-to-feed ratios were not affected by DDGS inclusion during any of the phases or overall.

A summary of the carcass traits is shown in Table 5. Because we attempted to kill the pigs at a common targeted BW of 120 kg, the final BW of the pigs was not different among the 4 treatment groups. Although HCW was slightly less in pigs fed the 2 greater concentrations of DDGS, unlike a reduced carcass yield reported in certain experiments, dressing percent was not affected ($P = 0.24$) by the amount of DDGS in the diet. Pigs fed the 2 greater amounts of DDGS had less backfat (linear, $P < 0.02$), but dietary treatment had no effect on LM area. Estimated fat-free lean in the carcass tended (linear, $P = 0.06$) to increase when DDGS was included in the diets.

Belly flex measurements, which indicate the softness and flexibility of the belly, were affected by the amount of DDGS in the diet (Table 5). Lateral flex measurements decreased linearly ($P < 0.001$) and vertical flex increased linearly ($P < 0.003$) as the DDGS was increased in the diet.

The fatty acid composition (expressed as a percentage of the total fatty acids) of the extracted fat from the inner and outer backfat tissue of pigs in the study is shown in Table 6. Linear ($P < 0.015$ to 0.001) changes in all of the fatty acids occurred in both inner and outer backfat as DDGS increased in the diet. The percentages of all of the SFA and MUFA decreased, whereas the percentages of the PUFA (C18:2, C18:3, C20:2, and C20:4) increased with increasing amounts of dietary DDGS. Linoleic acid (C18:2), which represented 93% of the total PUFA, was responsible for the greatest increase in PUFA in the fat of pigs fed diets containing DDGS. Although concentrations of most of the fatty acids differed between inner and outer backfat ($P < 0.05$ to 0.001), the responses to DDGS in the diet followed the same trend, with no evidence of any interaction between backfat site and diet.

The sums of the SFA and unsaturated fatty acids along with the sums of the MUFA and PUFA in the backfat are shown in Table 7. It is evident from the data in this table that the outer backfat had more total unsaturated fatty acids ($P < 0.001$) and PUFA ($P < 0.05$) and less total SFA ($P < 0.001$) compared with the inner backfat. Also evident from the data in Table 7 is that as the amount of DDGS increased in the diet, the percentages of total SFA and total MUFA decreased in both layers of backfat, and the percentages of total unsaturated and total PUFA increased (linear, $P < 0.001$).

The iodine values, calculated from the fatty acids in the extracted fat from the inner layer of backfat increased from 61.1 in the controls to 82.2 in pigs fed the greatest amount of DDGS (linear, $P < 0.001$). Outer backfat had greater iodine values than inner backfat ($P < 0.001$) but followed a similar trend, increasing from

Table 4. Performance traits of pigs fed distillers dried grains with solubles (DDGS) during 3 phases[1]

Item	DDGS, %				CV	Linear *P*-value
	0	15	30	45		
BW, kg						
Initial	32.6	32.7	32.4	32.5	1.91	0.5
End of phase I	60.4	60.7	59.8	59.7	2.59	<0.03
End of phase II	91.7	91.5	90.0	90.0	2.80	<0.02
End of phase III[2]	119.2	120.1	117.6	117.0	2.95	<0.02
End of phase III[3]	120.4	121.6	120.6	119.3	2.44	0.18
Phase I						
ADG,[4] g	950	964	921	920	5.43	<0.01
ADFI,[4] kg	2.18	2.21	2.15	2.15	4.82	0.23
G:F, g/kg	439	437	432	430	5.16	0.13
Phase II						
ADG, g	1,002	982	957	959	7.36	0.08
ADFI, kg	2.86	2.86	2.77	2.83	4.94	0.21
G:F, g/kg	351	345	346	340	5.84	0.25
Phase III						
ADG, g	897	926	901	882	8.71	0.44
ADFI, kg	3.14	3.17	3.11	3.10	7.20	0.42
G:F, g/kg	286	295	289	285	8.71	0.86
Final (constant-time basis)[2]						
ADG, g	944	953	924	915	4.89	<0.03
ADFI,[4] kg	2.73	2.76	2.68	2.70	4.61	0.15
G:F, g/kg	347	347	345	341	4.45	0.33
Final (constant-BW basis)[3]						
ADG, g	945	953	925	913	4.88	<0.02
ADFI,[4] kg	2.74	2.77	2.69	2.71	4.49	0.17
G:F,[5] g/kg	346	347	344	339	4.55	0.24

[1]Data based on 28 replications of 4 to 6 pigs per pen from 9 stations.

[2]All treatments within a given replication on test for the same time period (until the average pig BW in the control diet reached a targeted final BW).

[3]All pigs within a pen on test to a targeted final average pig BW for that pen.

[4]Cubic effect, $P < 0.05$.

[5]Station × treatment interaction, $P < 0.05$.

67.9 to 85.8, respectively (linear, $P < 0.001$). The mean iodine values of the inner and outer backfat increased linearly ($P < 0.001$) as the amount of DDGS in the diet increased.

Table 8 shows the iodine values (mean of inner and outer backfat) of pigs at the 9 participating stations. There were no differences in iodine values in backfat among stations ($P = 0.66$) in spite of the variation among stations in iodine values of control pigs, ranging from 59.3 (Wisconsin) to 66.9 (Nebraska). Most importantly, the linear increase in iodine values ($P < 0.001$) resulting from the increasing amounts of DDGS

Table 5. Carcass traits and belly firmness of pigs fed distillers dried grains with solubles (DDGS)[1]

Item	DDGS, %				CV	Linear *P*-value
	0	15	30	45		
BW at slaughter, kg	121.5	122.9	120.5	119.8	2.79	0.15
HCW, kg	90.8	91.9	89.9	89.0	2.82	<0.05
Dressing percent	74.8	74.8	74.7	74.3	1.44	0.24
Backfat,[2] mm	22.5	22.7	21.4	21.6	11.97	<0.02
LM area,[2] cm^2	47.4	47.4	46.1	45.4	5.97	0.16
Carcass fat-free lean,[2] %	51.9	52.2	52.4	52.1	2.81	0.06
Belly flex						
Lateral,[3] cm	11.9	8.6	8.4	6.6	25.8	<0.001
Vertical,[3] cm	26.1	27.4	28.2	28.7	6.59	<0.003

[1]Carcass data based on 28 replications of 2 pigs per pen from 9 stations. Belly flex means based on 12 replications of 2 pigs per pen from 6 stations.

[2]Station × treatment interaction, $P < 0.05$.

[3]A lower lateral score and a higher vertical score indicate a softer, more flexible belly.

Table 6. Fatty acid composition in inner and outer backfat of pigs fed distillers dried grains with solubles (DDGS)[1]

Item	DDGS, %				CV	Linear *P*-value
	0	15	30	45		
Inner backfat, % of total						
C14:0	1.20	1.14	1.03	0.95	8.71	<0.001
C16:0[2]	25.33	24.41	22.76	21.56	9.28	<0.001
C16:1[2,3]	2.31	2.09	1.28	1.28	27.43	<0.001
C18:0[2]	14.27	12.68	12.01	10.10	10.48	<0.001
C18:1[2]	43.22	40.29	38.28	35.58	5.93	<0.001
C18:2[4]	11.52	17.15	22.26	27.86	12.03	<0.001
C18:3[2]	0.43	0.53	0.55	0.63	14.64	<0.001
C20:0[2]	0.21	0.18	0.16	0.15	29.17	<0.006
C20:1	0.82	0.68	0.65	0.62	16.90	<0.001
C20:2	0.50	0.60	0.76	0.94	27.24	<0.001
C20:4[2]	0.15	0.19	0.19	0.23	22.73	<0.001
Outer backfat, % of total						
C14:0	1.22	1.11	1.04	0.93	11.07	<0.001
C16:0	23.52	22.41	20.98	19.48	7.48	<0.001
C16:1	3.25	2.87	2.39	2.10	16.48	<0.001
C18:0	10.56	9.69	8.85	7.85	10.37	<0.001
C18:1	45.63	43.33	41.36	39.37	7.18	<0.001
C18:2	13.56	18.16	22.86	27.51	12.26	<0.001
C18:3	0.54	0.60	0.60	0.67	15.55	<0.001
C20:0	0.14	0.13	0.13	0.12	23.37	<0.015
C20:1	0.81	0.71	0.68	0.65	13.75	<0.001
C20:2	0.52	0.67	0.80	0.97	11.45	<0.001
C20:4	0.17	0.20	0.22	0.24	19.17	<0.001

[1]Means based on 28 replications of 2 pigs per pen from 9 stations.
[2]Differed from outer backfat, $P < 0.001$.
[3]Cubic effect, $P < 0.05$.
[4]Differed from outer backfat, $P < 0.05$.

Table 7. Fatty acid composition and iodine value of lipids in inner and outer backfat of pigs fed distillers dried grains with solubles (DDGS)[1]

Item	DDGS, %				CV	Linear *P*-value
	0	15	30	45		
Fatty acids in inner backfat, % of total						
Saturated[2]	41.0	38.4	36.0	32.8	7.32	<0.001
Unsaturated[2]	58.9	61.5	64.0	67.1	4.31	<0.001
Monounsaturated[2]	46.3	43.1	40.2	37.5	6.06	<0.001
Polyunsaturated[3]	12.6	18.5	23.8	29.7	11.78	<0.001
Fatty acids in outer backfat, % of total						
Saturated[2]	35.4	33.4	31.0	28.4	7.46	<0.001
Unsaturated[2]	64.5	66.5	68.9	71.5	3.52	<0.001
Monounsaturated[2]	49.7	46.9	44.4	42.1	6.99	<0.001
Polyunsaturated[3]	14.8	19.6	24.5	29.4	11.86	<0.001
Fatty acids, average of inner and outer backfat, % of total						
Saturated	38.2	36.0	33.5	30.4	5.77	<0.001
Unsaturated	61.7	63.9	66.4	69.5	3.03	<0.001
Monounsaturated	48.0	44.9	42.3	39.7	5.22	<0.001
Polyunsaturated	13.7	19.0	24.1	29.7	11.17	<0.001
Iodine values in lipid						
Inner backfat[2]	61.1	68.2	74.7	82.2	5.43	<0.001
Outer backfat[2]	67.9	73.6	79.6	85.8	4.29	<0.001
Avg.	64.5	70.8	77.1	84.3	4.33	<0.001

[1]Means based on 28 replications of 2 pigs per pen from 9 stations.
[2]Inner vs. outer backfat, $P < 0.001$.
[3]Inner vs. outer backfat, $P < 0.05$.

Table 8. Mean iodine values of lipids in backfat of pigs fed distillers dried grains with solubles (DDGS)[1,2]

	DDGS, %			
Item	0	15	30	45
University of Wisconsin	59.3	72.5	74.6	83.8
University of Minnesota	62.5	67.4	77.0	82.3
University of Kentucky	64.8	70.9	76.6	84.4
North Carolina State University	65.1	67.7	79.1	82.1
Oklahoma State University	65.6	71.6	78.5	88.3
Purdue University	65.7	71.4	80.1	87.8
University of Missouri	65.8	72.6	78.1	81.7
The Ohio State University	65.9	72.9	72.2	83.9
University of Nebraska	66.9	71.4	77.1	83.2

[1]Average of inner and outer backfat. The stations are ranked from the least to the greatest iodine values in the backfat of pigs fed the control diet with no DDGS.

[2]CV = 4.32. Linear effect of dietary DDGS, $P < 0.001$. The effects of station and the station × treatment interaction were $P = 0.66$ and 0.63, respectively.

in the diet was consistent among stations as evidenced by a nonsignificant station × treatment interaction ($P = 0.63$).

To further evaluate the overall relationship between iodine values in backfat and the concentration of DDGS in the diet, the iodine values were plotted against dietary DDGS. Figure 2 shows that relationship based on the mean iodine values of the 9 stations. The linear regression of iodine values on the percentage of DDGS in the diet provided an excellent fit ($Y = 64.5 + 0.432X$; $R^2 = 0.917$) and indicates that iodine values increased 0.432 units for every 1% inclusion (i.e., 4.32 units for every 10% inclusion) of DDGS in the diet.

DISCUSSION

Numerous studies have been conducted to evaluate the nutritional value of DDGS in diets for swine. Most of the earlier work was conducted with DDGS as a coproduct of the beverage alcohol industry. In 1 study, inclusion of 20% beverage-based DDGS did not reduce pig performance of growing-finishing swine, but 40% DDGS resulted in poorer rate and efficiency of BW gain (Cromwell et al., 1983). However, results from the early studies were variable depending on numerous factors, one of which was likely the quality of the DDGS used in the experiments. Cromwell et al. (1993) reported that the feeding value of DDGS for swine and poultry was affected by the quality of the DDGS. In their studies, dark-colored DDGS, generally caused by overheating the DDGS during the drying process, resulted in poorer growth rates in growing pigs and chicks compared with light-colored DDGS. Similar findings were reported by Fastinger and Mahan (2006).

There has been a resurgence of research on evaluating dietary concentrations of newer types of DDGS that

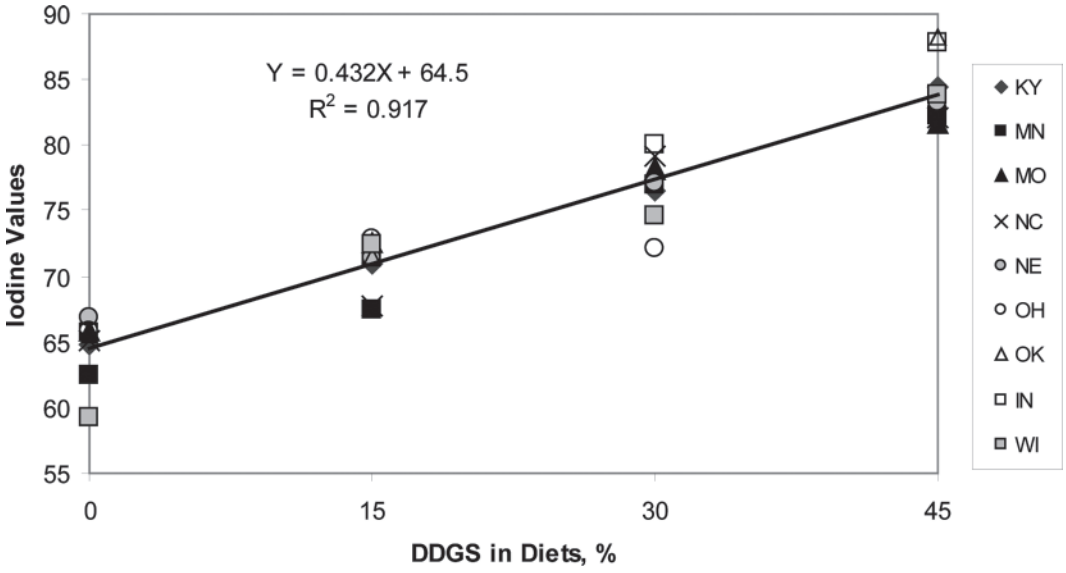

Figure 2. Iodine values in backfat (average of inner and outer backfat) of pigs fed corn distillers dried grains with solubles (DDGS) during the growing-finishing phase at 9 experiment stations. IN = Purdue University.

are coproducts of fuel alcohol production. Although it is thought that these newer generation distillery coproducts are less variable than the older generation products, variation in nutrient content has been reported (Spiehs et al., 2002). With respect to dietary concentrations of DDGS, Stein (2007) reviewed the literature and concluded that up to 20% DDGS could be used in diets for growing-finishing pigs without negatively affecting performance. He also reported that some swine producers were using greater amounts of DDGS (up to 35% in the diet) without compromising growth or carcass traits. In a more recent review, Stein and Shurson (2009) concluded that 30% DDGS could be used in growing-finishing diets without depressing performance, but this dietary amount does produce softer bellies. Recent studies by others (Whitney et al., 2006; White et al., 2009; Leick et al., 2010; Ulery et al., 2010; Xu et al., 2010) have shown that increased dietary DDGS in finishing diets increase iodine value in pork fat and produce soft bellies. Pork processors claim that soft bellies are difficult to process into bacon.

Our study showed that up to 45% of a high-quality DDGS can be included in diets without much effect on pig growth performance. The ability of the pigs in this study to efficiently utilize these greater amounts of DDGS may have been partially due to diets being formulated on a SID AA basis using supplements of Lys-HCl and Trp, which kept the dietary protein concentration from being excessive. Many of the earlier studies with greater amounts of DDGS involved diets that were formulated on a total Lys basis, and in some instances, AA supplements were not used, which resulted in very high concentrations of dietary CP.

Belly firmness was negatively affected in this study by feeding the greater amounts of DDGS. Objective flex measures indicated that the bellies were softer and more flexible when DDGS was fed, and that belly firmness decreased linearly with increasing amounts of DDGS in the diet. These changes are undoubtedly due to changes in the fatty acid composition of the belly. Although we did not sample the bellies for fatty acid analysis, backfat samples clearly showed that percentages of the SFA decreased and percentages of the total unsaturated fatty acids increased with increasing amounts of DDGS in the diet. In particular, the PUFA, especially linoleic acid (C18:2), more than doubled in the inner and outer backfat from pigs fed the 45% DDGS diet compared with the controls. These greater amounts of C18:2 caused the calculated iodine value to increase from 64.5 (average of inner and outer backfat) in control pigs to 84.3 in pigs fed the 45% DDGS diet.

Meat packers discriminate against carcasses with increased iodine values. Although there is no standard on the maximum acceptable iodine values, the National Pork Producers Council (2000) recommended a maximum iodine value of 70, whereas Boyd et al. (1997) listed an iodine value of 74 as a maximum. Based on the relationship of iodine values and concentration of DDGS in the diet ($Y = 64.5 + 0.432X$), DDGS inclusion rates of 13 and 22% would have resulted in iodine values of 70 and 74, respectively.

If feeding diets with large amounts of DDGS (such as the greatest amount used in the current study) is desired, a strategy that could be employed to keep the iodine value below these maximum ranges would be to withdraw it from the late finishing diet. A 3- to 4-wk period of elimination or reduced amount of DDGS in the finishing diet was reported to reduce fat iodine values in studies by Hill et al. (2008) and Xu et al. (2010). Ulery et al. (2010) reported that withdrawing DDGS from the diet and switching to a corn-soybean meal diet for the final 6 wk of the finishing period resulted in belly flex measures that were essentially the same as for pigs fed a corn-soybean meal diet throughout the growing-finishing period.

Inclusion of tallow in diets containing large amounts of DDGS to increase the proportion of dietary SFA, however, does not reduce the iodine value of carcass fat (Feoli et al., 2008; Ulery et al., 2010). In contrast, the addition of 1% CLA to diets containing 20 or 40% DDGS for 10 d before slaughter reduced iodine values of carcass fat (White et al., 2009).

In summary, these results show that up to 45% DDGS can be fed to growing-finishing pigs without having much effect on growth performance or carcass leanness. However, this relatively large amount of DDGS in the diet does result in a greater proportion of PUFA, greater iodine values in the backfat, and softer, more flexible bellies.

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