Corn DDGS in growing-finishing diets for swine

Growth performance and carcass characteristics of growing swine fed corn distiller's dried grains with solubles originating from a modern mid-western ethanol plant[1]

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ABSTRACT: A growth performance and carcass evaluation study was conducted to evaluate the recommended maximum inclusion rate of corn distiller's dried grains with solubles (DDGS) in grow-finish diets when formulated on a total amino acid basis. A total of 240 (28.4 ± 0.8 kg) crossbred pigs ((York x Landrace) x Duroc) were randomly assigned to one of four dietary treatment sequences in a 5-phase grow-finish feeding program (24 pens, 10 pigs/pen, 6 replications/treatment). Dietary treatments consisted of corn-soybean meal diets containing 0, 10, 20, or 30% DDGS. All diets were formulated to contain equivalent total lysine, ME, calcium, and phosphorus levels within each phase. Pigs were

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weighed and feed disappearance determined every 2 wks. Average body weight was used to determine when dietary phase changes were made for each individual pen. Pigs were slaughtered and carcass data collected when average pen weight reached 114 kg. Pigs fed the 20 or 30% DDGS diets had reduced ADG ($P < .10$) compared to 0 or 10% DDGS, but ADFI was unaffected by dietary treatment ($P > .10$). Feed/gain increased when pigs were fed 30% DDGS ($P < .10$) compared to 0, 10, and 20% DDGS inclusion levels. Dressing % decreased linearly ($P < .03$) with increasing dietary DDGS level, but slaughter weight was also lower for pigs fed 20 or 30% DDGS ($P < .05$). Loin depth was lower in pigs fed the 30% DDGS diets ($P < .10$), but backfat depth and % lean did not differ between treatments ($P > .10$). Color measurements, ultimate pH and visual evaluations (color, firmness, and marbling scores) of the longissimus dorsi muscle did not differ among treatments ($P > 0.05$). Water holding capacity traits, including 24-h drip loss, cooking loss, and total moisture loss, were not different ($P > 0.05$) between treatments. However, differences were detected between 0 and 20% DDGS treatments for 11-d purge loss ($P < 0.05$) . Dietary treatment did not affect ($P > 0.05$) Warner-Bratzler shear force values of cooked loin chops. Results from this study suggest that when grow-finish diets are formulated on a total amino acid basis, less than 20% DDGS should be included in the diet for optimal performance and carcass composition. Dietary inclusion levels of 20% or greater may provide satisfactory performance and carcass composition, however, if diets are formulated on a digestible amino acid basis. Feeding DDGS in swine finishing diets did not have any detrimental effects on pork muscle quality in this study.

Key Words: Distiller's dried grains with solubles, Swine, Growth, Carcass

Introduction

Poor amino acid balance and digestibility have resulted in conservative and somewhat variable recommendations involving maximum inclusion rates of distillers dried grains with solubles (DDGS) in grow-finish swine diets. In the Feed Co-Products Handbook, Harper and Forsyth (1998) recommend that no more than 7.5% DDGS be used in diets for growing pigs (40-120 lbs) and no more than 10% DDGS be used in diets for finishing pigs (120 lbs-market). The Pork Industry Handbook (1998) recommends no more than 10% DDGS be included in diets for growing and finishing pigs. In a literature review by Newland and Mahan (1990), however, the authors suggest that up to 20% DDGS can be added to grow-finish diets without reducing pig performance, if synthetic lysine and tryptophan are added to the diet.

Results from a previous study (Whitney et al., 2000) demonstrated that total and apparent digestible lysine level in DDGS from modern (built after 1990) mid-western (MW) ethanol plants is higher than values published in NRC (1998). Apparent digestible threonine and tryptophan levels were also higher in MW DDGS than published values, indicating that greater inclusion rates of MW DDGS may be possible before requiring the addition of synthetic amino acids to maintain proper amino acid balance. Thus, a growth performance study was conducted to determine if adding increasing amounts of DDGS to grow-finish diets in a phase feeding program will provide equal growth performance and/or carcass quality when diets containing DDGS are formulated to contain the same level of total lysine, phosphorus and ME.

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 crossbred pigs initially weighing 28.4 ± .8 kg were randomly allotted within gender and ancestry to one of 24 pens in a 4 x 3 factorial arrangement. Distiller's dried grains with solubles (DDGS) inclusion level (0, 10, 20, or 30%) in the diet and initial bodyweight class [low (23.2 kg), medium (28.1 kg), and high (33.8 kg)] served as the main factors for the grow-finish performance trial. A 5-phase grow-finish feeding program (6 replications/treatment) was utilized to evaluate growth performance and carcass characteristics. Diet switches were made weekly on an individual pen basis, when the average pen weight was within 2.25 kg of the target end weight for each phase.

Experimental diet composition and calculated nutrient analysis are provided for grower and finisher periods, respectively, in Tables 1 and 2. Diets within each phase of growth were formulated to contain equivalent levels of total lysine, ME, calcium, total phosphorus, vitamins and trace minerals. Total amino acid values obtained from a previous MW DDGS experiment (Whitney et al., 1999) were used in the formulation of experimental diets. The ME value used for DDGS was 3520 kcal/kg and the ME value for soybean oil was 7260 kcal/kg. Dietary total lysine levels were formulated at 1.10, 1.00, 0.85, 0.72, and 0.64% for phases I-V, respectively, based on mixed sex pigs averaging 0.77 kg

gain/day, 3.10 F/G, and 52% lean (NRC, 1998). All diets were formulated to meet or exceed a minimum ratio of 100, 55, 65, and 20 for total lysine, methionine+cystine, threonine, and tryptophan, respectively, and contained 0.15% synthetic lysine. Soybean oil was added to the control diets at a rate of 4%, 4%, 3%, 1.5%, and 1.5% for phases I through V, respectively. The higher amounts used in phases I-III were primarily to provide ample supplemental energy to support optimum growth, particularly during hot weather, whereas the lower levels used during phases IV-V were provided 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 equivalent dietary ME concentration and preventing total dietary fat levels from exceeding 7.5%. DDGS was provided by AL-CORN Clean Fuel (Claremont, MN). This ethanol plant was chosen as the source of DDGS due to its similarity with several newer (built after 1990) ethanol plants located in the upper midwestern region of the United States. The vitamin-trace mineral premix was prepared and delivered monthly. Feed samples were obtained from each batch of feed manufactured and frozen until laboratory analysis could be performed.

Growth and Carcass Data Collection

Pigs were weighed and feed disappearance measured every two weeks during the trial to determine growth performance, feed intake, and feed conversion. When the average pen weight reached 114 kg, pigs were tattooed and shipped to Morrell Foods (Sioux Falls, SD), slaughtered, and tissue samples and carcass data collected. This occurred over 4 different

days, with the first group being shipped at 91 days of age. At that time, growth performance and feed intake were determined for all pigs, and then also summarized for each pen using market weight data. At the time of slaughter, hot carcass weight was determined and 10th rib fat thickness, loin depth, and percent lean were measured with a Fat-O-Meater (SFK Technology, Copenhagen, Denmark) by plant personnel.

Approximately 24 h postmortem, 112 bellies (average internal temperature of 6.7°C) from the left sides of two slaughter groups were retrieved and subjected to a firmness test. The firmness test consisted of measuring belly length on a flat surface (L) and then placing it skin-side down on a stainless steel smoke stick. The distance between the two ends of the suspended belly (D) was then measured. Belly firmness score was assigned to each belly and was equal to the upper angle of the isosceles triangle created by hanging the belly over the smoke stick and was calculated as belly firmness score = $\cos^{-1}[(0.5(L^2) – D^2)/(0.5(L^2))]$. Belly thickness, not including the skin, was determined by inserting a probe at the scribe line midway between the cranial and caudal ends. Fat samples were taken midway between the cranial and caudal ends of the belly at a point just dorsal of the scribe line and were packaged and transported to the South Dakota State University Meat Laboratory and analyzed for iodine absorption number by the Hanus method using approximately 0.5 g of dissolved fat (AOAC, 1998). Samples were analyzed twice and an average iodine number was calculated and recorded for each carcass.

Vacuum packaged boneless loin sections (n = 110) from the left sides of carcasses from two 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, loins were weighed, removed from vacuum packages, allowed to drip for approximately 15 min, and

re-weighed. 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 longissimus dorsi muscle in the caudal end of the cranial loin section was measured with a Meatcheck 160 pH meter (Sigma Electronic GmbH, Erfurt, Germany) equipped with a puncture-type combination pH electrode (LoT406-M6-DXK-S7/25, Mettler-Toledo GmbH, Urdorf, Switzerland).

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 (-16ºC) 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 on drip loss chops using a Minolta Chroma Meter CR-310 colorimeter (Minolta Corp., Ramsey, NJ) with a D65 illuminant. 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 on a bandsaw and placed in freezer storage (-16ºC) for 1 to 2 weeks. Chops were then thawed for 24 h at 1ºC and cooked with an impingement oven (Model 1132-000-A, Lincoln Impinger, Fort Wayne, IN) at 190.5ºC for 10.5 min. The resulting average final internal temperature of the chops was 68ºC. Cooked chops were cooled to room temperature (20ºC) before three 1.27-cm-diameter cores per chop (six cores per animal) were removed parallel to the longitudinal orientation of the muscle fibers. Individual cores were sheared once on a Warner-Bratzler

shear machine. 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 data were analyzed (SAS, 1989) as a completely randomized block design. Model included initial weight group (light, medium, and heavy) and dietary treatment (0, 10, 20, and 30% DDGS). Least-squares means were calculated and differences between treatment means (P < .10) determined. Orthogonal comparisons across DDGS level were conducted to determine linear and/or quadratic trends to increasing DDGS level in the diet.

Carcass data was analyzed (SAS, 1989) as a completely randomized block design. The model included slaughter group (2 groups), dietary treatment (0, 10, 20, and 30% DDGS), and gender. Analysis of belly firmness score included belly thickness as a linear covariate. Least-squares means were calculated and separated (P < 0.05) using pair-wise *t*-tests. Additionally, multiple regression analyses was conducted and included regression of iodine number on belly firmness score, regression of belly thickness on belly firmness score and regression of iodine number and belly thickness on belly firmness score.

Results and Discussion

Growth Performance

Least squares means (by treatment and initial weight group) for bodyweight and growth performance responses are provided in Table 3. Initial body weight and variation in body weight were similar across dietary treatment groups. Including 20 or 30% DDGS in the diet resulted in similar feed intakes (*P* > 0.10) compared to the 0 or 10% dietary level, but growth rate decreased (817 and 808 vs. 863 and 858 g/d, *P* < 0.001) over the initial 91-d feeding period. This resulted in poorer G/F for pigs fed 30% DDGS compared to pigs fed 0 or 10% DDGS diets (*P* < 0.05). Similar trends were observed over the entire feeding period. Days on test were similar (n = 103.5) for all dietary treatment groups. Final slaughter weight, however, was greater for pigs fed the 0 and 10% DDGS diets (117.1 and 117.8 kg) compared to pigs fed 20 or 30% DDGS (114.1 and 112.1 kg), although the experiment was designed to minimize differences in final bodyweight (*P* < 0.10).

These results suggest that growing-finishing swine will readily consume diets containing up to 30% MW DDGS. Therefore, MW DDGS appears to be an acceptable substitute for corn and soybean meal in a growing-finishing diet without negatively affecting voluntary food intake. However, when diets are formulated on a total amino acid basis, including 20% or greater MW DDGS results in poorer growth rate and feed efficiency. This is not surprising, considering that MW DDGS, although relatively high in crude protein and many essential amino acids (Whitney et al., 1999), has an amino acid profile similar to its base grain, corn, resulting in an abundance of nonessential amino acids in excess of the pig's nutritional needs. Also, the apparent amino acid digestibility coefficients of MW DDGS have been shown to be greater (Whitney et al., 2000) than previous published estimates (NRC, 1998), but still less than the soybean meal it is partially replacing in a total

amino acid corn-soybean meal formulation. Therefore, a combination of inadequate supplies of available lysine and other amino acids, in association with increased energy utilization to deaminate and excrete excess amino acids (and therefore not available for growth), would be expected to result in decreased growth performance and poorer feed conversion when diets are formulated on a total amino acid basis.

Initial weight group had a significant effect on growth performance and feed intake, resulting in increased ADG and ADFI (*P* < 0.01) with increased initial weight over the entire study. Similarly, number of days required to reach market weight decreased (*P* < 0.001) with increased initial body weight, with the lightest group of pigs requiring 17.5 extra days compared to the heaviest group. Final market weight was similar across initial weight groups (*P* = 0.90), but less variation in weight was observed in the medium weight group (CV = 6.83) compared to the light and heavy groups (CV = 8.81 and 8.94, respectively; *P* < 0.07). No treatment x initial weight group interactions were observed (*P* > 0.30) for the growth performance responses measured.

Carcass Composition

Carcass composition data were collected from 193 of the 240 pigs that were fed during the growth performance study. Least squares means for initial carcass weight and composition are provided in Table 4. Number of barrows evaluated was similar across treatments (*P* > 0.10), but 4 more gilts were evaluated from the 30% DDGS treatment compared to the other 3 treatments, resulting in a difference in gilts and total number of pigs evaluated across treatments (*P* < 0.04). Similar to ending growth performance data,

slaughter weights were greater for pigs on the 0 and 10% DDGS treatments (117.1 and 118.9 kg) compared to pigs fed the 20 or 30% DDGS diets (112.9 and 112.3 kg; *P* < 0.10). This resulted in greater hot carcass weights for pigs fed 0 or 10 compared to 20 or 30% DDGS diets (*P* < 0.10). As DDGS level increased in the diet, carcass weight linearly decreased (*P* < 0.002). This was due, however, to differences in slaughter weight (*P* < 0.001), and not dietary treatment (*P* = 0.78). These differences in slaughter weight, therefore, resulted in greater carcass dressing percent values from pigs on the 0 and 10 vs. 20 and 30% dietary DDGS treatments (*P* < 0.10).

Fat depth was largely unaffected by dietary treatment (*P* < 0.10), but did tend to increase with increased slaughter weight (*P* < 0.01). Similarly, percent carcass lean was unaffected by dietary treatment (*P* < 0.10), but tended to decrease with increasing slaughter weight (*P* < 0.01). Increasing dietary DDGS level tended to linearly decrease loin depth (*P* < 0.02). Pigs fed the 0% DDGS diets had greater loin depths compared to pigs fed the 30% DDGS diets (*P* < 0.10), with intermediate loin depths from pigs fed either 10 or 20% DDGS. The differences in loin depth can be largely attributed to differences in slaughter weight (*P* < 0.08) and not necessarily to differences in dietary treatment (*P* = 0.59). These results suggest that, although growth performance was negatively affected by increased DDGS level, carcass composition was largely unaffected when factoring the differences in slaughter weight. Decreases in percent body lean and backfat accretion were of a similar magnitude, therefore, with increasing DDGS level in the diet.

Fat and Muscle Quality

Iodine number increased linearly (*P* < 0.05), and thus carcass fat became more unsaturated, as the level of DDGS was increased in the diet (Table 5). It has been well established that feeding diets that contain an unsaturated fat source can alter the level of saturation in pork fat. Lea et al. (1970) characterized quality pork fat 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 raw soybeans (Pontif et al., 1987) or barley- and maize-based diets (Lucas et al., 1960; Lawrence, 1974). The effect of DDGS feeding on iodine number was reflected in the analysis of belly firmness score (Table 5). Lower belly firmness scores indicated that bellies from pigs that were fed 30% DDGS were softer (*P* < 0.05) than bellies from pigs fed 0 or 20% DDGS. Softer bellies were most likely a consequence of elevated levels of unsaturated lipids.

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 presented in tabular form). Thus, degree of carcass fatness had a larger effect on belly firmness than did fat composition.

Color measurements of L* were not different (*P* > 0.05) among dietary treatments (Table 6). Likewise, visual evaluations of the longissimus dorsi muscle did not differ between treatments for color score, firmness score, or marbling score. Moreover, ultimate pH was not different (*P* > 0.05) between treatments. Water holding capacity traits, including 24-h drip loss, cooking loss, and total moisture loss, were not different (*P* > 0.05) between treatments. However, differences were detected between 0 and 20% DDGS

treatments for 11-d purge loss (*P* < 0.05). Dietary treatment did not affect (*P* > 0.05) Warner-Bratzler shear force values of cooked loin chops. Therefore, feeding DDGS in swine finishing diets did not have any meaningful effects on pork muscle quality.

Implications

Corn distiller's dried grains with solubles originating from modern ethanol plants located in the upper mid-western region of the U.S. is an abundant feed ingredient source that can be incorporated at levels up to 10% of the diet, replacing corn, soybean meal, and dicalcium phosphate in conventional swine grower-finisher diets. When diets are formulated on a total amino acid basis, it appears that inclusion levels of 20% or higher result in decreased growth performance and poorer feed conversion. Including DDGS at levels up to 30% into a grower-finisher phase feeding sequence does not appear to affect muscle composition or quality, but does decrease the saturation of fat, resulting in softer bellies, and may negatively affect further processing traits. Inclusion levels of 20% or greater may provide satisfactory growth performance and carcass composition, however, if diets are formulated on a digestible amino acid basis.

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

	Early grower diets[a] DDGS inclusion, %				Late grower diets[b] DDGS inclusion, %			
Item	**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
Vit-TM premix[c]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Lysine HCL	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Analyzed composition								
ME, kcal/kg	3366	3412	3326	3344	3359	3395	3320	3315
Calcium, %	0.70	0.76	0.68	0.70	0.73	0.70	0.67	0.70
Phosphorus, %	0.59	0.61	0.58	0.59	0.58	0.61	0.58	0.57
Crude protein, %	17.7	18.2	19.6	19.8	17.1	17.8	19.2	20.2
Lysine, %	0.90	0.98	1.01	1.06	1.06	1.04	1.02	1.04
Methionine and cystine, %	0.51	0.64	0.70	0.73	0.59	0.65	0.67	0.74
Threonine, %	0.58	0.69	0.74	0.76	0.64	0.68	0.74	0.79
Tryptophan, %	0.20	0.18	0.21	0.20	0.18	0.22	0.20	0.20

[a] Diets were formulated to contain 3435 kcal/kg of ME, 1.10% total lysine, 0.65% Ca, and 0.55% total P.

[b] Diets were formulated to contain 3445 kcal/kg of ME, 1.00% total lysine, 0.62% Ca, and 0.54% total P.

[c] Supplied per kg of premix: 1,466,667 IU vitamin A as retinyl acetate, 246,400 IU vitamin D_3, 6,138 IU vitamin E as dl-a-tocopherol acetate, 979 mg vitamin K as menadione dimethylpyrimidinol bisulfite, 1,467 mg riboflavin, 8,800 mg niacin, 5,867 mg pantothenic acid as d-calcium pantothenate, 6.6 mg vitamin B_{12}, 141 mg iodine as EDDI, 99 mg selenium as sodium selenite, 59,840 mg zinc as zinc oxide, 59,840 mg iron as ferrous sulfate, 3,960 mg copper as copper sulfate, and 1,980 mg manganese as manganese oxide.

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

	Early finisher diets[a] DDGS inclusion, %				Middle finisher diets[b] DDGS inclusion, %				Late finisher diets[c] DDGS inclusion, %			
Item	**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
Vit-TM premix[d]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
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												
ME, kcal/kg	3331	3302	3291	3274	3320	3300	3287	3285	3247	3364	3322	3313
Calcium, %	0.70	0.77	0.81	0.74	0.78	0.77	0.81	0.79	0.74	0.72	0.67	0.68
Phosphorus, %	0.56	0.63	0.60	0.55	0.65	0.59	0.55	0.57	0.49	0.52	0.49	0.48
Crude protein, %	13.3	15.2	16.5	17.4	12.6	13.3	14.7	15.6	12.3	12.7	13.1	14.0
Lysine, %	0.82	0.86	0.88	0.84	0.72	0.73	0.75	0.70	0.64	0.62	0.62	0.57
Methionine and cystine, %	0.50	0.55	0.64	0.71	0.46	0.49	0.58	0.63	0.44	0.45	0.53	0.57
Threonine, %	0.49	0.56	0.64	0.71	0.47	0.48	0.58	0.64	0.45	0.45	0.53	0.55
Tryptophan, %	0.16	0.17	0.16	0.18	0.14	0.15	0.16	0.17	0.13	0.13	0.14	0.13

[a] Diets were formulated to contain 3412 kcal/kg of ME, 0.85% total lysine, 0.62% Ca, and 0.52% total P.

[b] Diets were formulated to contain 3359 kcal/kg of ME, 0.72% total lysine, 0.60% Ca, and 0.51% total P.

[c] Diets were formulated to contain 3364 kcal/kg of ME, 0.64% total lysine, 0.59% Ca, and 0.50% total P.

[d] Supplied per kg of premix: 1,466,667 IU vitamin A as retinyl acetate, 246,400 IU vitamin D_3, 6,138 IU vitamin E as dl-a-tocopherol acetate, 979 mg vitamin K as menadione dimethylpyrimidinol bisulfite, 1,467 mg riboflavin, 8,800 mg niacin, 5,867 mg pantothenic acid, as d-calcium pantothenate, 6.6 mg vitamin B_{12}, 141 mg iodine as EDDI, 99 mg selenium as sodium selenite, 59,840 mg zinc as zinc oxide, 59,840 mg iron as ferrous sulfate, 3,960 mg copper as copper sulfate, and 1,980 mg manganese as manganese oxide.

Table 3. Least squares means for bodyweight, ADG, ADFI, and G/F responses to dietary treatments and initial weight groups.

	DDGS inclusion, %					Initial wt group				*P* -value		
Item	**0**	**10**	**20**	**30**	**SEM**	**Low**	**Med**	**High**	**SEM**	**Trt**	**Grp**	**Trt x Grp**
Number of pigs	59	60	60	60	---	80	80	79	---	---	---	---
In wt, kg	28.56	28.58	28.17	28.24	0.35	23.17[a]	28.14[b]	33.85[c]	0.30	0.77	0.001	0.93
CV, %	8.28	8.98	8.48	9.75	1.05	8.53[a]	7.11[a]	10.99[b]	0.91	0.77	0.03	0.45
Day 0 - 91												
ADG, g	863[a]	858[a]	817[b]	808[b]	9.08	813[a]	826[a]	867[b]	4.54	0.001	0.001	0.35
ADFI, g	2288	2279	2206	2252	40.86	2116[a]	2220[b]	2429[c]	31.78	0.51	0.001	0.48
G/F	0.377[a]	0.377[a]	0.370[a,b]	0.360[b]	0.004	0.384[a]	0.373[b]	0.356[c]	0.004	0.05	0.001	0.60
D 91 wt, kg	106.13	106.55	102.49	101.74	0.77	97.18[a]	103.36[b]	112.14[c]	0.68	0.002	0.001	0.27
CV, %	6.58[a]	7.45[a]	8.18[a]	10.45[b]	0.68	8.66[a,b]	6.9[a]	8.94[b]	0.59	0.01	0.06	0.73
Overall												
ADG, g	863[a]	858[a]	826[b]	808[b]	4.54	822[a]	825[a]	873[b]	4.54	0.001	0.001	0.31
ADFI, g	2379	2374	2311	2356	36.32	2288[a]	2324[a]	2456[b]	31.78	0.59	0.01	0.53
G/F	0.363[a]	0.360[a]	0.358[a]	0.343[b]	0.004	0.359	0.355	0.355	0.004	0.02	0.71	0.67
Final wt, kg	117.14[a]	117.80[a]	114.11[b]	112.11[b]	1.40	115.35	114.86	115.66	1.21	0.05	0.90	0.83
CV, %	6.92[a]	7.15[a]	8.30[a]	10.40[b]	0.74	8.81[a]	6.83[b]	8.94[a]	0.64	0.02	0.07	0.96
# of days	103.5	103.5	103.5	103.5	1.17	112.0[a]	104.0[b]	94.5[c]	1.01	1.00	0.001	1.00

[a,b]Means within a row with different superscripts differ (*P* < 0.10).

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

Item	DDGS inclusion, %				SEM	ANOVA *P* -value			Trend *P* -value	
	0	10	20	30		Trt	Wt	Trt x Wt	Linear	Quad
Number of pigs	45	48	50	50	0.64	0.04	0.47	0.04	0.28	0.50
Number of barrows	24	27	29	28	0.46	0.63	0.90	0.60	0.33	0.48
Number of gilts	21	21	21	25	0.53	0.04	0.31	0.04	0.59	0.42
Slaughter wt, kg	117.10[a]	118.92[a]	112.89[b]	112.27[b]	1.66	0.03	---	---	0.02	---
Carcass wt, kg	85.91[a]	86.85[a]	80.68[b]	80.55[b]	1.23	0.78	0.001	0.75	0.002	0.01
Dressing %	73.37[a]	73.03[a]	71.50[b]	71.74[b]	0.50	0.77	0.83	0.74	0.003	0.01
Fat depth, mm	21.33	21.68	20.97	20.58	0.65	0.40	0.01	0.41	0.32	0.46
Loin depth, mm	56.57[a]	54.15[a,b]	54.40[a,b]	51.72[b]	1.24	0.59	0.08	0.60	0.02	0.07
Lean, %	52.63	52.15	52.60	52.53	0.42	0.16	0.01	0.17	0.93	0.80

[a,b]Means within a row with different superscripts differ ($P < 0.10$).

Table 5. Fat quality characteristics of swine fed differing levels of distiller's dried grains with solubles.

	DDGS inclusion, %				
Item	**0**	**10**	**20**	**30**	**RMSE**
Belly thickness, cm	3.15[c]	3.00[c,d]	2.84[c,d]	2.71[d]	0.56
Belly firmness score[a], degrees	27.3[c]	24.4[c,d]	25.1[c]	21.3[d]	6.3
Adjusted belly firmness score[b], degrees	25.9[c]	23.8[c,d]	25.4[c]	22.4[d]	5.4
Iodine number	66.8[c]	68.6[d]	70.6[e]	72.0[e]	3.4

[a]Belly firmness score = cos-1[(0.5(L2) – D2)/(0.5(L2))], where L = belly length measured on a flat surface and D = the distance between the two ends of a suspended belly; higher belly firmness scores indicate firmer bellies.

[b]Belly firmness score adjusted for belly thickness.

[c,d,e]Means within a row with different superscripts differ ($P < 0.10$).

Table 6. Muscle quality characteristics of swine fed differing levels of distiller's dried grains with solubles.

Item	DDGS inclusion, % 0	10	20	30	RMSE
L^{*}[a]	54.28	55.10	55.81	55.51	2.87
Color score[b]	3.17	3.15	3.05	3.12	0.81
Firmness score[c]	2.21	2.04	2.06	2.08	0.52
Marbling score[d]	1.89	1.85	1.72	1.91	0.61
Ultimate pH	5.61	5.56	5.60	5.61	0.16
11-d purge loss, %	2.06[f]	2.37[f,g]	2.84[g]	2.54[f,g]	1.15
24-h drip loss, %	0.70	0.67	0.71	0.74	0.17
Cooking loss, %	18.66	18.50	18.26	18.77	2.58
Total moisture loss[e], %	21.42	21.54	21.81	22.05	3.13
Warner-Bratzler shear, kg	3.40	3.44	3.33	3.30	0.53

[a]0 = black to 100 = white.

[b]1 = pale pinkish gray to white; 2 = grayish pink; 3 = reddish pink; 4 = dark reddish pink; 5 = purplish red; 6 = dark purplish red (NPPC, 1999).

[c]1 = soft; 2 = firm; 3 = very firm (NPPC, 1999).

[d]Visual scale approximates percent intramuscular fat content (NPPC, 1999).

[e]Total moisture loss = 11-d purge loss + 24-h drip loss + cooking loss.

[f,g]Means within a row with different superscripts differ ($P < 0.05$).