7-1-2008

Corn distillers dried grains (DDGS) for growing-finishing swine

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Title: Corn distillers dried grains (DDGS) for growing-finishing swine – **NPB #06-142**

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Date Submitted: July 1, 2008

Industry Summary: A nutrition study was conducted to investigate the feeding value of DDGS for growing-finishing swine. Specifically, growing-finishing diets were developed that contain 0 (control), 5, 10, and 15% DDGS. These dietary treatments were maintained during a three-phase (Phase-1, 50 to 100 lb, 1.0% lysine; Phase-2, 100 to 170 lb, 0.80% lysine, and Phase-3, 170 to 230 lb, 0.65% lysine) growing-finishing period. Pigs had ad libitum access to feed and water during the entire experimental period. Pigs and feeders were weighed every 2 wk and ultrasound determination of backfat and longissimus muscle area was conducted every 4 wk. All pigs were harvested when body weight reached approximately 230 lb. Post-harvest, backfat, longissimus muscle area, and standard carcass measurement were recorded. In addition, a backfat sample was retained for the analysis of fatty acid profile. Longissimus muscle samples were retained for taste-panel evaluation. Overall, growth performance decreased as dietary DDGS inclusion increased from 0 to 15%. This reduction in performance may have been partially explained or exacerbated by the elevated fiber concentration detected in the source of DDGS used in this study. Dressing percentage, chemical composition, color and sensory characteristics of the LM did not change due to the inclusion of dietary DDGS up to 15%. These results suggest that the inclusion of increasing levels of DDGS in diets of finishing pigs from the University of Nebraska-Lincoln (UNL) nutrition line did not affect carcass characteristics; however, as DDGS inclusion increased HCW was reduced. The dietary inclusion of DDGS may result in an increase in total unsaturated fatty acid and a decrease in total saturated fatty acid concentrations.

Scientific Abstract: Two-hundred and forty pigs growing-finishing pigs were used to evaluate the feeding value of distillers dried grains with solubles (DDGS). Treatments consisted of 0, 5, 10 and 15% dietary DDGS inclusion. Treatments did not affect average daily gain (ADG), average daily feed intake (ADFI) or gain:feed (G:F) during the grower 1 period ($P > 0.05$). During the grower 2 period ADG and ADFI linearly decreased as DDGS increased ($P < 0.05$). No differences among treatments were detected throughout the feeding phase finisher 1 for ADG, ADFI, and G:F ($P > 0.05$). During the finisher 2 feeding phase, there was a linear reduction in ADG and ADFI in response to dietary DDGS inclusion ($P = 0.01$). Overall, linear reductions in ADG, ADFI and G:F were recorded as dietary DDGS increased ($P < 0.05$). Backfat and longissimus muscle area decreased as dietary DDGS concentration increased ($P < 0.05$). Overall, growth performance was reduced as dietary DDGS inclusion increased from 0 to 15%. The reduction in performance may have been partially explained or exacerbated by the elevated fiber concentration detected in the source of DDGS used in this study. Live weight and hot carcass weight decreased as dietary DDGS increased ($P < 0.05$). Dressing percentage did not differ

among treatments ($P = 0.72$). After 10 d of retail display, no differences were observed among treatments for color or color change ($P > 0.05$). No differences in shear force were observed ($P = 0.34$). Total unsaturated fatty acids increased and total saturated fatty acids decreased ($P < 0.05$) as dietary DDGS increased. Treatments did not affect sensory characteristics ($P > 0.05$). The results of this investigation suggest that dietary DDGS inclusion altered fatty acid profile of the backfat of pigs by reducing total saturated fatty acid and increasing total unsaturated fatty acid concentration. Increasing concentration of dietary DDGS did not affect color, chemical composition or sensory characteristics of the LM.

Introduction: Approximately, 30% of Nebraska's corn use in 2004-'05 was identified as dedicated to be "processed" (Nebraska Corn Board). Of the 309 million (mil) bushels identified for processing, 136 mil bushels were used in the manufacturing of ethanol (44%). Furthermore, the amount used to produce ethanol is over twice the amount dedicated exclusively for pigs (62 mil bushels). If the assumption that approximately two-thirds of the corn kernel by weight is starch (and completely converted to ethanol), a remainder of 45 mil bushels of co-product is available for use by the livestock industry.

Historically, the feedlot industry in Nebraska has utilized the majority of dry-milling co-products; however, there has been an increasing interest in use of these co-products for nonruminants (e.g., growing-finishing pigs). Based on previous research (primarily conducted at South Dakota State University and the University of Minnesota), a role for dry-milling co-products (DDGS) has been identified. However, it does appear that the maximum inclusion level of DDGS is limited (<20% of the diet) for growing-finishing pigs, and the use of DDGS for growing-finishing pigs has not been investigated using Nebraska sources of DDGS. In addition, the use of DDGS in growing-finishing diets still requires evaluation on and the basis of how growth performance and carcass quality are affected.

Objective: 1) To determine the feeding value and effect on carcass composition of diets containing 5, 10, and 15% DDGS for growing-finishing pigs.

Materials and Methods:

GROWTH PERFORMANCE

Animals and facilities

This experimental protocol was reviewed and approved by the Institutional Animal Care and Use of the University of Nebraska-Lincoln. Two hundred and forty barrows and gilts [(Danbred × NE white line) × Danbred] were used for this 16-week study. The initial average weight was 49.2 lb. Five barrows and five gilts were housed in each of 24 pens, and there were 6 replicates for each of the 4 dietary treatments. Pigs were housed in a 24-pen building equipped with automatic environmental control. Pens dimensions were 4.95 × 15.84 ft and each pen was equipped with automatic feeder and waterer. The flooring was half solid concrete and half concrete slats. Pigs had ad libitum access to feed and water throughout the experimental period.

Dietary treatments

Pigs received a four phase dietary growing-finishing regime (Tables 1 and 2). The diets included 0, 5, 10 or 15% DDGS. Crystalline lys was incorporated into diets containing DDGS in order to maintain a constant total lys concentration among diets. Other nutrient concentrations were formulated to meet or exceed allowances identified in the Nebraska-South Dakota Swine Nutrition Guide.

Data and sample collection

Pigs and feeders were weighed at 0800 at the beginning of the experiment and biweekly thereafter. Feed disappearance was estimated by the difference between feed offered and feed remaining on the feeder at the end of each biweekly period. Body weight gain was estimated by the difference between the weight at the beginning and at the end of each biweekly period. Average daily gain (ADG), average daily feed intake (ADFI) and ADG:ADFI (G:F) were estimated based on the individual biweekly body weight gain and feed disappearance. At the beginning of the experiment and every 8 wk thereafter, ultrasound was used to measure backfat thickness (BF) and longissimus muscle area (LMA) at the 10^{th} rib.

Statistical analysis

The MIXED procedure of SAS (SAS Inst. Inc. Cary, NC.) was used to analyze the data. Contrasts were designed to evaluate linear and quadratic responses to addition of DDGS to dietary treatments. Pen was considered the experimental unit and the model was a completely randomized design. Pen was considered a random effect.

MEAT QUALITY

Carcass data collection

At the end of the feeding phase all pigs were transported to a commercial pork packing facility located approximately 30 miles from the University of Nebraska Swine Research Unit. Pigs were weighed before entering (live weight; LW) and before leaving the harvesting floor (hot carcass weight; HCW). Dressing percentage (DP) was calculated using the following formula DP = ((LW / HCW)×100). Carcasses were subjected to a standard spray-chilling procedure for 24 h. Before entering the fabrication floor, a cut was made on the right side of the carcasses between the 10^{th} and 11^{th} rib and the LM was traced on acetate paper and LMA was measured. Tenth-rib backfat depth (TRBF) and last-rib backfat depth (LRBF) were measured. A backfat sample was obtained perpendicular to the 10^{th} rib, submerged in liquid nitrogen and maintained at -112^{o}F until analyzed for fatty acid profile. Two pigs from each pen were randomly selected prior to harvesting, carcasses were identified on the chilling floor, marked in the vertebrae, and the loin (410 pork loin; NAMP, 1997) from the right side of the carcass was collected. The collected loins were individually vacuum packed and transported to the Meat Science Laboratory at the University of Nebraska. Seven days post mortem, the loins were boned and a section of LM (412B pork loin, boneless, center-cut, eight ribs; NAMP, 1997) was removed and divided in 2 sections (Fig. 1). A total of nine 1-in sections were obtained for color determination, shear force estimation, sensory characteristics evaluation, and chemical composition.

Color determination

The two sections of the LM used for color determination were packed in Styrofoam trays, wrapped with PVC film, and maintained at 34^{o}F under fluorescent light illumination for 10 d. Color spectrometry measurements L*, a*, and b* (representing lightness, redness, and yellowness respectively) were obtained through the packing film on five sites on each section at the beginning (d 0) of the 10 d-color trial and daily thereafter using a Hunter Lab® Mini Scan XE plus (Model 45/0-L, Reston, VA) handheld colorimeter. The calibration of the colorimeter was performed daily using black and white tiles. The change in total color (E) was calculated as [((L* at d 10 – L* at d 0)^2 + (a* at d 10 – a* at d 0)^2 + (b* at d 10 – b* at d 0)^2)^{½}; Minolta, 1998]. This formula was developed in order to better describe the changes in color that would occur during periods of retail display.

Warner-Bratzler shear force analysis.

The loin sections used for Warner-Bratzler shear force (WBSF; AMSA, 1995) were vacuum-packed and maintained at -4^{o}F until analysis. Before the analysis chops were allowed to thaw, cooked to an internal temperature of 158^{o}F on a Hamilton Beach Grill (Washington, NC), and cooled for 4h at 35.6^{o}F. During the cooking process temperature was monitored using thermocouples. Three cores of 0.5 in^2 from each section were removed parallel to the arrangement of the muscle fiber. Cores were sheared parallel to the muscle fiber using an Intron Universal Testing Machine (Model 55R1123, Canton, MA) equipped with a Warner-Bratzler shear attachment. The speed for the test was 250 mm/min.

Fatty acid profile

Fat samples were extracted in hexane and methyl esters were formed. The mass ratio of fatty acids were quantified using a gas chromatograph (Hewlett-Packard, Model 5890, Farmington Hills, MI).

Sensory evaluation

Chops were cooked and sensory evaluation was conducted using 40 consumer panelists, recruited from the Department of Animal Science and the Department of Food Science and Technology at the University of Nebraska-Lincoln. The chops were cooked using an electric grill to an internal temperature of 158^{o}F. Once cooked, chops were trimmed of excess fat. Samples of 1 in^2 were obtained and maintained warm until served to the panelists. A descriptive scale was used to determine the effect of DDGS inclusion on pork quality and flavor. Panelists used an unstructured line-scale to evaluate the attributes provided in Table 5.

Statistical analysis

Carcass characteristics, chemical composition, fatty acid profile and sensory characteristics were analyzed as a complete randomized design using the MIXED procedure of SAS (SAS Inst., Inc., Cary, N.C.). Each pig was considered an experimental unit and pen was considered a random effect. Color data were analyzed as repeated measures in time using the MIXED procedure of SAS. Pig was considered the experimental unit and tray was considered a random effect.

VII – VIII. ***Results and Discussion*** The growth performance responses of growing-finishing pigs to varying dietary concentrations of DDGS are provided in Table 3. Final weight decreased linearly as DDGS increased (P = 0.02). During the grower 1 period, treatments did not affect ADG, ADFI, or G:F (P > 0.05). Treatment did affect ADG during the grower 2 period (P = 0.02). A linear (P = 0.03) response of ADG to dietary DDGS concentration indicated that ADG decreased as dietary DDGS inclusion increased. Also during grower 2 treatment effected ADFI (P = 0.01). We observed a linear reduction in ADFI as dietary DDGS concentration increased (P = 0.04). Feed efficiency was not affected by dietary treatment (P = 0.25). No differences among treatments were detected throughout the feeding phase finisher 1 for ADG, ADFI, and G:F (P > 0.05). During the finisher 2 period, despite the lack of treatment effect (P = 0.06), we observed a linear reduction in ADG and G:F in response to dietary DDGS inclusion (P = 0.01). For the overall period, ADG and G:F differed among treatments (P = 0.01) and a linear reduction in ADG and G:F was recorded as dietary DDGS increased (P = 0.01). Although not significant (P = 0.11), increased dietary DDGS concentration resulted in a linear reduction in ADFI (P = 0.04).

Backfat and LMA results are provided in Table 4. No difference among treatments was detected for BF or LMA at d 0, 56 or 112 (P > 0.05); however at d 112 BF and LMA were reduced as dietary DDGS increased (P < 0.05). A number of studies have shown no reduction in growth performance on DDGS inclusion up to 20% of the diet. Our results contradict previous findings.

We initially screened DDGS samples for CP and lysine content. After the completion of the trial, analysis indicated the neutral detergent fiber (NDF) concentrations in the DDGS used were approximately 45 to 50% (See Table 1 for diet composition). Normally DDGS contains about 30 to 40% NDF. The additional concentration of cell wall content found in the DDGS we used could explain the reduction in performance associated with increased DDGS inclusion observed in our study. This observation highlights the importance of screening DDGS samples for all nutrient components (including; CP, lysine, fat and fiber).

Table 1. Ingredient, calculated and analyzed composition of growing pig diets, as-fed basis

	Grower 1 (45-80 lb)				Grower 2 (80-130 lb)			
	DDGS[c], %							
Item, %	0	5	10	15	0	5	10	15
Corn	69.39	67	64.54	62.05	74.00	71.68	69.42	66.97
Soybean meal, 46.5% CP	25.40	22.8	20.25	17.75	21.70	19.00	16.25	13.70
Tallow	2.50	2.50	2.50	2.50	2.00	2.00	2.00	2.00
Dicalcium phosphate	1.15	1.05	1.00	0.90	0.85	0.75	0.70	0.60
Limestone	0.90	0.95	0.97	1.02	0.82	0.90	0.92	0.97
Salt	0.22	0.20	0.17	0.15	0.22	0.20	0.17	0.15
Vitamin premix[a]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Trace mineral mix[b]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-Lysine·HCl	0.13	0.20	0.26	0.32	0.10	0.16	0.23	0.30
DDGS[c]	0.00	5.00	10.00	15.00	0.00	5.00	10.00	15.00
Analyzed Composition								
CP[d], %	17.24	17.10	17.45	17.41	15.82	16.15	16.07	16.10
GE[e], Mcal[f]/lb	1.80	1.83	1.86	1.88	1.80	1.83	1.85	1.88
NDF[f], %	10.77	13.14	17.37	17.11	12.17	14.10	12.59	14.26
EE[g], %	4.87	5.42	5.62	6.00	4.41	4.84	5.26	5.63
Calculated Composition								
Lysine, %	1.00	1.00	1.00	1.00	0.88	0.88	0.88	0.88
CP[d], %	18.00	18.00	18.00	18.00	16.50	16.50	16.50	16.50
ME[e], Mcal[f]/lb	1.55	1.53	1.52	1.51	1.55	1.53	1.52	1.51

[a]Supplied per kilogram of diet at 0.2% inclusion: vitamin A supplied as retinyl acetate, 4,400 IU; cholecalciferol, 440 IU; a-tocopherol acetate, 24 IU; menadione sodium bisulfite, 3.5 mg; riboflavin, 8.8 mg; d-pantothenic acid, 17.6 mg; niacin, 26.4 mg; vitamin B_{12}, 26.4 mg. [b]Supplied per

kilogram of diet at 0.1% of inclusion: Zn (as ZnS_4O), 85 mg; Fe (as $FeSO_4{\bullet}H_2O$), 85 mg; Mn (as MnO), 20 mg; Cu (as $CuSO_4{\bullet}5\,H_2O$), 7 mg; I (as $Ca(IO_3){\bullet}H_2O$), 0.17 mg; Se (as Na_2SeO_3), 0.17 mg. [c]DDGS = Corn distillers dried grain with solubles. [d]CP = Crude protein. [e]ME = Metabolizable energy. [f]NDF = Neutral detergent fiber. [g]EE = Ether extract.

Table 2. Ingredient, calculated and analyzed composition of finishing pig diets, as-fed basis

	Finisher 1 (130-190 lb)				Finisher 2 (190-250 lb)			
	DDGS[c], %							
Item	0	5	10	15	0	5	10	15
Corn	80.27	77.65	75.31	72.95	85.1	82.6	80.27	77.79
Soybean meal, 46.5% CP	15.60	13.25	10.60	8.00	11.00	8.50	5.85	3.35
Tallow	2.00	2.00	2.00	2.0	2.00	2.00	2.00	2.00
Dicalcium phosphate	0.75	0.67	0.60	0.50	0.60	0.55	0.47	0.40
Limestone	0.80	0.85	0.90	0.95	0.80	0.83	0.87	0.90
Salt	0.22	0.20	0.17	0.15	0.22	0.20	0.18	0.17
Vitamin premix	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral mix	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L-Lysine·HCl	0.10	0.12	0.16	0.20	0.02	0.06	0.10	0.13
DDGS[c]	0.00	5.00	10.00	15.00	0.00	5.00	10.00	15.00
Analyzed Composition								
CP[d], %	13.53	13.67	13.93	14.33	12.04	11.94	12.11	12.16
GE[e], Mcal/lb	1.80	1.84	1.86	1.88	1.82	1.84	1.85	1.88
NDF[f], %	8.80	10.24	11.67	14.27	9.59	12.92	13.17	15.35
EE[g], %	4.80	5.34	5.78	6.18	5.12	5.47	5.76	6.13
Calculated Composition								
Lysine, %	0.72	0.72	0.72	0.72	0.55	0.55	0.55	0.55
CP[d], %	14.20	14.20	14.20	14.20	12.30	12.30	12.30	12.30
ME[e], Mcal/lb	1.55	1.54	1.52	1.51	1.55	1.54	1.52	1.51

[a]Supplied per kilogram of diet at 0.15% inclusion: vitamin A supplied as retinyl acetate, 3,300 IU; cholecalciferol, 330 IU; a-tocopherol acetate, 18 IU; menadione sodium bisulfite, 2.64 mg; riboflavin, 6.60 mg; d-pantothenic acid, 13.23 mg; niacin, 19.80 mg; vitamin B_{12}, 19.80 mg. [b]Supplied per kilogram of diet at 0.1% of inclusion: Zn (as ZnS_4O), 85 mg; Fe (as $FeSO_4 \cdot H_2O$), 85 mg; Mn (as MnO), 20 mg; Cu (as $CuSO_4 \cdot 5\ H_2O$), 7 mg; I (as $Ca(IO_3) \cdot H_2O$), 0.17 mg; Se (as Na_2SeO_3), 0.17 mg. [c]DDGS = Corn distillers dried grain with solubles. [d]CP = Crude protein. [e]ME = Metabolizable energy. [f]NDF = Neutral detergent fiber. [g]EE = Ether extract.

Table 3. Response and effect of dietary DDGS[a] inclusion on growth performance of growth finishing pigs

	DDGS[a], %					*P*-value		
Item	0	5	10	15	SEM[b]	Treatment	Linear	Quadratic
No. of pigs	60	60	60	60				
No. of pens	6	6	6	6				
Initial weight, lb	49.44	49.42	48.85	49.27	0.32	0.57	0.47	0.51
Final weight, lb	260.65	252.96	249.96	240.84	4.56	0.02	0.02	0.54
Grower 1 (week 1 to 4)								
ADG[c], lb	1.66	1.61	1.53	1.56	0.04	0.24	0.08	0.43
ADFI[d], lb	3.49	3.43	3.34	3.43	0.05	0.32	0.30	0.18
G:F[e]	0.47	0.47	0.45	0.45	0.01	0.39	0.10	0.89
Grower 2 (week 5 to 8)								
ADG[c], lb	1.82	1.60	1.72	1.60	0.05	0.02	0.03	0.38
ADFI[d], lb	4.83	4.40	4.58	4.50	0.08	0.01	0.04	0.05
G:F[e]	0.37	0.36	0.37	0.35	0.01	0.25	0.17	0.61
Finisher 1 (weeks 9 to 12)								
ADG[c], lb	1.93	1.94	1.85	1.80	0.06	0.83	0.11	0.65
ADFI[d], lb	6.29	5.85	5.91	5.84	0.17	0.23	0.11	0.28
G:F[e]	0.30	0.33	0.31	0.30	0.01	0.29	0.77	0.16
Finisher 2 (weeks 13 to 16)								
ADG[c], lb	2.05	1.92	1.83	1.79	0.67	0.06	0.01	0.51
ADFI[d], lb	7.04	7.09	6.86	6.73	0.17	0.44	0.14	0.60
G:F[e]	0.29	0.27	0.26	0.26	0.01	0.04	0.01	0.13
Overall (week 1 to 16)								
ADG[c], lb	1.86	1.76	1.73	1.68	0.03	0.01	0.01	0.39
ADFI[d], lb	5.40	5.14	5.13	5.11	0.09	0.11	0.04	0.20
G:F[e]	0.34	0.34	0.33	0.33	0.01	0.01	0.01	0.43

[a]DDGS = Corn distillers dried grain with solubles. [b]SEM=Standard error of the mean. [c]ADG = Average daily gain. [d]ADFI = Average daily feed intake. [e]G:F = Gain to feed ratio

Table 4. Response and effect of dietary DDGS[a] inclusion on BF[b] and LMA[c] of growing-finishing pigs

	DDGS concentration, %					*P*-value		
Item	0	5	10	15	SEM[d]	Treatment	Linear	Quadratic
No. of pigs	60	60	60	60				
No. of pens	6	6	6	6				
Initial weight, lb	49.44	49.42	48.85	49.27	0.32	0.57	0.47	0.51
Final weight, lb	260.65	252.96	246.96	240.84	4.56	0.02	0.01	0.54
Initial (d 0)								
BF[b], in	0.27	0.29	0.28	0.28	0.01	0.19	0.38	0.21
LMA[c], in^2	1.45	1.48	1.45	1.49	0.12	0.33	0.22	0.84
d 56								
BF[b], in	0.47	0.44	0.48	0.43	0.01	0.08	0.31	0.43
LMA[c], in^2	3.46	3.29	3.31	3.24	0.07	0.21	0.06	0.52
Final (d 112)								
BF[b], in	0.81	0.76	0.79	0.71	0.03	0.05	0.03	0.52
LMA[c], in^2	5.62	5.53	5.45	5.28	5.16	0.13	0.02	0.93

[a]DDGS=Corn distillers dried grain with solubles. [b]BF=Back fat at 10[th] rib. [c]LMA=Longissimus muscle area at 10[th] rib. [d]SEM=Standard error of the mean.

Carcass traits are shown in Table 6. A negative linear response to DDGS concentration was recorded for LW and HCW ($P < 0.05$), which indicates that LW and HCW decreased as dietary DDGS increased. Dressing percentage was not affected ($P = 0.72$) by dietary DDGS. These results are different from those reported in other studies that showed reductions in DP as DDGS concentration increased. Treatments did not affect LMA, LRBF and TRBF ($P > 0.05$).

The results of the chemical analysis and color of LM are provided in Table 7. Protein, moisture, fat, and ash were not affected by dietary DDGS inclusion ($P > 0.05$). Shear force did not differ among treatments ($P = 0.34$). At d 0 and 10 there was no difference among treatments ($P > 0.05$) for redness (a*), yellowness (b*), lightness (L*), and color change (E). These results indicate that during the 10-d experimental period, pigs receiving increasing dietary concentration of DDGS showed a pattern in change of color (E) similar to the control diet (0 % DDGS).

Table 8 shows the fatty acid profile of backfat samples. Mysistic, palmitoleic, stearic, oleic, vaccenic, and α-linolenic were not affected by dietary DDGS concentration ($P > 0.05$). Treatments affected palmitic acid concentration ($P = 0.03$) and exhibited a linear reduction in mass % as dietary DDGS inclusion increased ($P = 0.01$). Linoleic acid concentration was affected by treatment ($P = 0.01$); increasing dietary DDGS resulted in increments in mass % of this fatty acid in backfat ($P = 0.01$). Despite the lack of significant treatment effect ($P = 0.06$), increments in the concentration of DDGS in the diet of finishing pigs resulted in a linear reduction in the concentration of total saturated fatty acids (TSFA; $P = 0.01$). Increasing concentration of DDGS resulted in increased relative TUFA concentration in backfat samples ($P = 0.01$). Reports in the literature indicate that a reduction in the content of saturated fatty acids in adipose tissue occurs when sources of unsaturated fatty acids are included in the diet of pigs. Our results agree with those reports because we observed a decrease in TSFA and an increase in TUFA as dietary DDGS concentration increased. This alteration in the saturation of backfat may be the consequence of increased concentration of unsaturated fatty acids in the diets as dietary DDGS concentration increased.

The effects of DDGS inclusion on taste characteristics of the longissimus muscle of finishing barrows are provided in Table 9. The inclusion of increasing concentration of DDGS in the diets did not affect general appearance, texture, chewiness, juiciness, pork flavor, off-flavor, aftertaste, and overall acceptability of longissimus muscle ($P > 0.05$). A significant effect of treatment was detected for aftertaste off-flavor ($P = 0.01$). Off flavor was more pronounced as dietary DDGS increased ($P = 0.01$). In general, increasing dietary DDGS had minimal effects on pork sensory characteristics.

Figure 1. Longissimus muscle sections of the loins used for shear force, color determination, sensory characteristics, and chemical analysis

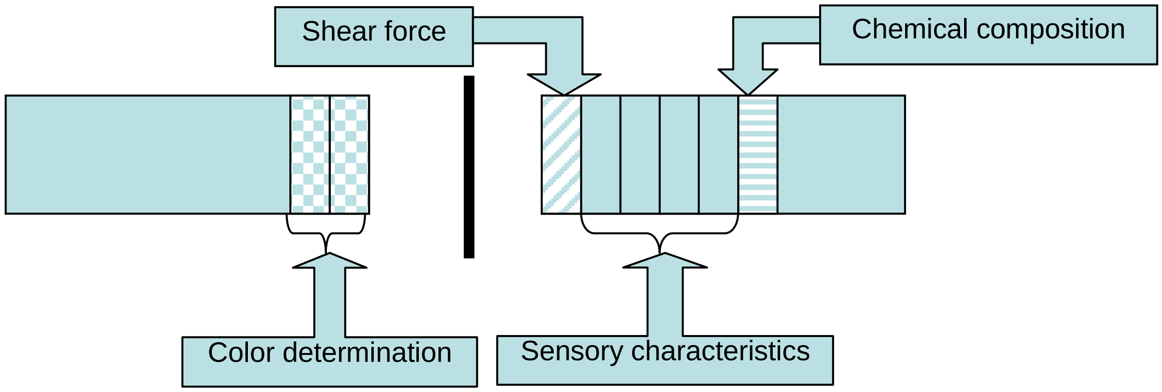

Table 5. Attribute, magnitude and description and scale of sensory characteristics.

Attribute	Magnitude: 0 mm	Magnitude: 150 mm	Comments
Appearance	Very non-uniform	Very uniform	Color of interior meat
Toughness	Very tough	Very tender	During the first bite
Chewiness	Very hard to breakdown	Very easy to breakdown	During chewing
Juiciness	Very dry	Very moist	
Pork flavor	Lacking	Intense	
Off-flavor	Lacking	Intense	
Aftertaste pork flavor	Lacking	Intense	
Aftertaste off flavor	Lacking	Intense	
Overall acceptability	Very undesirable	Very desirable	

Table 6. Response and significance of dietary DDGS[a] inclusion on final weight and carcass characteristics of growing-finishing pigs.

	DDGS[a], %					*P*-value		
Item	0	5	10	15	SEM[b]	Treatment	Linear	Quadratic
No. of pigs	13	11	12	11				
Live weight, lb	273.25	266.60	257.64	250.07	5.12	0.02	0.02	0.92
Hot carcass weight, lb	203.95	197.49	190.72	184.39	3.93	0.01	0.01	0.98
Dressing, %	74.64	74.10	74.02	73.72	0.57	0.72	0.28	0.83
Last rib BF[c], in	1.04	0.99	0.98	0.94	0.28	0.14	0.02	0.94
10th rib BF, in	0.94	0.76	0.85	0.85	0.10	0.68	0.69	0.40
LMA[d], in^2	7.82	8.02	7.59	7.25	0.20	0.07	0.02	0.19

[a]DDGS = Corn distillers dried grain with solubles. [b]SEM = Standard error of the mean [c]BF = Backfat. [d]LMA = Longissimus muscle area

Table 7. Response and significance of dietary [a]DDGS inclusion on the composition, shear force and color of the Longissumus muscle of growing-finishing pigs.

	[a]DDGS, %					*P*-value		
Item	0	5	10	15	SEM[b]	Treatment	Linear	Quadratic
Composition, %								
Crude protein	22.50	22.69	22.59	22.55	0.21	0.89	0.94	0.55
Moisture	71.90	71.31	70.73	72.23	0.50	0.17	0.84	0.04
Ash	1.12	1.14	1.18	1.16	0.02	0.32	0.11	0.41
Fat	3.87	4.12	4.86	3.04	0.49	0.08	0.38	0.03
Shear force, lb	6.7	7.03	6.37	6.92	0.28	0.34	0.99	0.66
Color (d 0)								
a*, (redness)	20.84	20.84	20.41	20.57	0.42	0.71	0.50	0.85
b*, (yellowness)	17.68	17.67	17.52	17.30	034	0.89	0.43	0.77
L*, (lightness)	54.31	54.07	54.72	54.49	0.43	0.84	0.75	0.99
Color (d 10)								
a*, (redness)	17.16	18.34	17.66	17.10	0.62	0.71	0.68	0.13

b*, (yellowness)	16.31	17.02	16.96	16.41	0.46	0.89	0.91	0.17
L*, (lightness)	54.08	55.14	55.91	56.07	0.72	0.84	0.22	0.97
E[c]	4.17	2.81	3.03	4.07	0.64	0.32	0.97	0.70

[a]DDGS = Corn distillers dried grain with solubles. [b]SEM = Standard error of the mean. [c]E = Change in color.

Table 8. Response and significance of dietary DDGS[a] inclusion on fatty acid profile of finishing pigs.

	DDGS[a], %					*P*-value		
Item	0	5	10	15	SEM[b]	Treatment	Linear	Quadratic
Fatty acid, mass %								
Myristic, (14:0)	1.47	1.37	1.38	1.36	0.37	0.18	0.07	0.31
Palmitic, (16:0)	25.16	24.32	24.57	23.36	0.41	0.03	0.01	0.66
Palmitoleic, (16:1)	2.23	2.30	2.24	2.25	0.10	0.95	0.99	0.75
Stearic, (18:0)	13.55	12.44	12.64	12.00	0.54	0.24	0.07	0.66
Oleic, (18:1)	38.86	40.15	39.62	39.68	0.46	0.25	0.35	0.19

Vaccenic, (18:1)	4.20	4.29	4.24	4.20	0.11	0.92	0.91	0.55
Linolenic, (18:2)	10.03	10.69	10.93	12.49	0.47	0.01	0.01	0.34
α-linolenic, (18:3)	0.40	0.39	0.37	0.40	0.01	0.68	0.99	0.31
Others	4.07	4.00	3.97	4.21	0.18	0.81	0.64	0.42
Total saturated fatty acids	40.18	38.13	38.60	36.74	0.88	0.06	0.01	0.91
Total mono-unsaturated fatty acids	45.30	46.76	46.10	46.13	0.60	0.41	0.49	0.24
Total poly-unsaturated fatty acids	10.43	11.09	11.30	12.90	0.49	0.01	0.01	0.34

[a]DDGS = Corn distillers dried grain with solubles. [b]SEM = Standard error of the mean.

Table 9. Response and effect of dietary [a]DDGS inclusion on sensory characteristics of Longissumus muscle of growing-finishing pigs.

	[a]DDGS, %					*P*-value		
Item	0	5	10	15	SEM[b]	Treatment	Linear	Quadratic
Attribute[c], mm								
General appearance	97.35	88.97	88.03	94.85	5.34	0.58	0.69	0.18

Toughness	71.97	65.95	67.19	79.50	5.61	0.33	0.36	0.11
Chewiness	79.74	75.60	76.78	81.18	5.51	0.87	0.88	0.43
Juiciness	73.23	78.90	82.05	75.73	4.88	0.60	0.62	0.22
Pork flavor	83.00	82.95	80.11	79.86	4.57	0.93	0.54	0.98
Off-flavor	43.13	43.79	43.85	58.62	5.87	0.17	0.07	0.22
Aftertaste pork flavor	80.58	81.45	72.90	69.18	4.80	0.19	0.04	0.62
Aftertaste off-flavor	45.53	40.03	40.32	61.86	5.61	0.01	0.05	0.01
Overall acceptability	83.00	75.87	80.51	74.92	5.01	0.54	0.31	0.80

[a]DDGS = Corn distillers dried grain with solubles. [b]SEM = Standard error of the mean. [c]Attribute description provided in Table 5.