Title: Characteristics and Eating Quality of Bacon and Sausage from Finishing Pigs Fed Medium and High Levels of Distillers Dried Grains with Solubles (DDGS) from Ethanol Production
NPB # 08-094

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Industry Summary:

An experiment involving 60 crossbred pigs was conducted at the University of Kentucky to assess the effects of feeding high levels of corn distillers dried grains with solubles (DDGS) on performance of growing-finishing pigs from 76 to 265 lb body weight, and on carcass and belly firmness, fatty acid composition of the fat, slicing efficiency of cured bacon, and eating quality of bacon slices, bratwurst sausage, and loin chops.

Fortified corn-soybean meal diets containing 0, 15, 30 or 45% DDGS were fed to growing-finishing pigs in three phases. A common source of DDGS analyzing 26.3% crude protein, 0.96% lysine, and 9.7% fat was used at each station. Diets were formulated to contain 0.83, 0.70, and 0.58% true ileal digestible lysine during the three phases with diets changed at 135 and 202 lb, respectively. The DDGS replaced corn and soybean meal, and crystalline lysine and tryptophan were added to maintain constant true ileal digestible levels of the amino acids in each phase. All pigs from each pen were killed for carcass and belly flex measurements. Samples of backfat and belly fat were obtained for fatty acid analysis and determination of iodine values.

Growth rate and feed intake were not affected by level of DDGS; however, efficiency of feed utilization decreased in pigs fed the higher levels of DDGS ($P < 0.02$). Backfat was reduced (but not significantly) and loin eye area increased ($P < 0.05$) in pigs fed DDGS, but carcass fat-free lean percentage was not affected by diet.

Bellies of the carcasses were measured for firmness. Flex measures indicated that the bellies became progressively more flexible and less firm as level of DDGS increased in the diets (linear, $P < 0.01$). Saturated and monounsaturated fatty acids in subcutaneous and belly fat decreased linearly ($P < 0.001$) and polyunsaturated fatty acids increased linearly ($P < 0.001$) with increasing DDGS in the diet. Iodine values (calculated from the fatty acid data) of outer backfat were 63, 70, 75, and 79 for the four treatment groups, a linear response to DDGS level fed ($P < 0.001$).

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Slicing efficiency of cured bacon slabs was not affected by the softer bellies. In fact, the quality of the fresh bacon slices was improved ($P < 0.001$) in bellies from pigs fed DDGS in which the fat was softer and more unsaturated. Cooking shrink and distortion scores of cooked bacon were similar for the four treatment groups.

Eating quality of cooked bacon, bratwurst sausage, and loin chops as tested by an eight-member panel did not differ among pigs fed the four DDGS diets. There was no indication that tenderness, texture, juiciness, or off-flavor was impacted by dietary treatment.

The results of this study showed that rather high levels of DDGS (up to 45% DDGS in the diet) can be fed to growing-finishing pigs without having much of an effect on growth rate; however, the amount of feed required per unit of gain was increased with increasing amounts of DDGS in the diet. Carcass leanness was not greatly affected by level of DDGS; however, the high levels of DDGS in the diet resulted in higher proportions of unsaturated fatty acids in the body fat, higher iodine values in the backfat and belly fat, and softer, more flexible bellies. These responses were linearly ($P < 0.01$) related to the amount of DDGS in the diet. Regardless of the changes in fat composition, the slicing efficiency of cured bacon slabs, quality measures of fresh sliced bacon, and eating quality of bacon, bratwurst sausage, and loin chops did not seem to be negatively affected by feeding 30 to 45% DDGS to growing-finishing pigs.

This study was supported with the National Pork Checkoff.

Scientific Abstract:

An experiment involving 60 crossbred pigs (3 replications of 5 pigs/pen) was conducted to assess the effects of dietary levels of DDGS on pig performance from 35 to 120 kg BW, and on belly firmness, fatty acid composition of the fat, slicing efficiency of the bacon, and eating quality of bacon, sausage, and loin chops. Fortified corn-soybean meal diets containing 0, 15, 30 or 45% DDGS were fed in 3 phases. A common source of DDGS (supplied by ADM, Decatur, IL) analyzing 89% DM, 26.3% CP, 0.96% Lys, 0.18% Trp, 9.7% fat, 34.6% NDF, 0.03% Ca, and 0.86% P was used. Diets were formulated to contain 0.83, 0.70, and 0.58% true ileal digestible (TID) Lys during the 3 phases with diets changed at 61 and 91 kg BW, respectively. DDGS replaced corn and soybean meal, and up to 0.22% L-Lys and 0.04% Trp were added to maintain constant TID levels in each phase. All of the pigs were killed and fat was collected from the midline and belly for fatty acid (FA) analysis and I value. Growth rate and feed intake were not affected by level of DDGS, but efficiency of feed utilization decreased with DDGS inclusion. Backfat was reduced slightly and LM area was increased (quadratic, $P < 0.05$) with increasing amounts of DDGS, but carcass fat-free lean was not affected by diet. Flex measures indicated less firm bellies (linear, $P < 0.01$) as DDGS levels increased. Saturated and monounsaturated FA in subcutaneous and belly fat decreased ($P < 0.001$) and polyunsaturated FA increased ($P < 0.001$) with increasing DDGS in the diet. Iodine values (calculated from the FA data) of outer backfat were 63, 70, 75, and 79, respectively for the four treatment groups (linear, $P < 0.001$). Slicing efficiency was not affected by the softer bellies and, interestingly, quality of fresh bacon slices was improved ($P < 0.001$) in bellies from pigs fed DDGS in which the fat was softer and more unsaturated. Eating quality of cooked bacon, bratwurst sausage, and loin chops did not differ among pigs fed the four DDGS diets. In this study, feeding diets with up to 45% DDGS did not have major effects on pig performance, but resulted in softer bellies and higher iodine values in backfat lipids. Pork quality, however, was not markedly affected by level of DDGS. This project was funded by the National Pork Checkoff.

Introduction:

Numerous ethanol plants have cropped up the past few years and others will be coming on-line during the next several years. These plants have a high demand for corn which has resulted in a substantial increase in corn prices this past year. Large amounts of DDGS are being produced as a by-product of ethanol production in these plants. Previous research at the University of Kentucky (Cromwell et al., 1983) and elsewhere has shown that relatively large amounts of DDGS originating from beverage alcohol plants can be used in growing-finishing diets without depressing performance. In addition, large variation in quality of DDGS has been found to exist (Cromwell et al., 1993; Spiehs et al., 2002).

Stein (2007) reviewed the literature on studies involving the feeding of DDGS for swine and found that the data were inconsistent with respect to the maximum amount of DDGS from ethanol plants that can be included in swine diets without negatively affecting performance or carcass firmness. His conclusions were that many swine producers are currently using up to 20% DDGS in finishing diets, but some producers are using greater inclusion rates, up to 35% DDGS, in diets without affecting performance or carcass quality. He further concluded that more research is needed to evaluate moderate to high levels of DDGS in diets on growth performance and belly firmness of hog carcasses.

A recent collaborative study that was funded by the National Pork Board and conducted at nine universities (NCCC-42 Committee on Swine Nutrition) showed that high levels of DDGS, up to 45% of the diet, could be fed to growing-finishing pigs without depressing performance if the diets were formulated on a true ileal digestible lysine basis and if the diets were supplemented with lysine and tryptophan in order to keep the crude protein of the diet from becoming excessive; however, carcasses firmness decreased and iodine levels of the backfat increased with the higher levels of DDGS (Cromwell et al., 2009).

Although studies have clearly shown that belly firmness is reduced when high levels of DDGS are fed to pigs, little data exist on the effect of the softer carcasses on slicing efficiency of cured bellies and eating quality of bacon from these bellies. In addition, the data are meager on the effects of softer carcasses on shelf life and eating quality of pork sausage and loin chops. This study should provide some insight on these possible effects.

Objectives:

The objectives of this study were to determine the effects of feeding moderate to high levels of DDGS to growing-finishing pigs on post-harvest carcass quality, belly firmness, processing characteristics of cured bacon, shelf life, and eating quality of pork (bacon, sausage, and loin chops). Specifically, we determined if up to 30 or 45% DDGS can be incorporated into corn-soybean meal diets formulated on a true ileal digestible lysine basis without having a negative effect on carcass quality and belly firmness to the point that it deters post-harvest processing characteristics. Also, we wanted to determine if high levels of DDGS would have such a negative effect on fat unsaturation that it would deter from the shelf life and eating quality of bacon, sausage, and loin chops.

Materials and Methods:

An experiment involving 60 crossbred pigs was conducted at the University of Kentucky as part of a larger study involving eight other experiment stations within the North Central region (NCCC-42 Committee on Swine Nutrition; formerly the NCR-42 Committee on Swine Nutrition) (Cromwell et al., 2009).

The study was designed to evaluate four dietary treatments consisting of a corn-soybean meal diet and three additional diets containing 15, 30, or 45% DDGS. The diets were fed to growing-finishing pigs from 76 to 265 lb body weight in three phases. The intent was to determine if moderate to high levels of DDGS could be fed without depressing performance of swine or negatively affecting carcass quality, belly firmness, and eating quality of bacon, sausage, and loin chops.

A common source of DDGS obtained from a single plant was obtained for the study. The DDGS was supplied by Archer Daniel Midland, Decatur, IL. The DDGS was analyzed at a commercial laboratory and the results are shown in Table 1. The dry matter, crude protein, crude fat, and amino acid levels were typical of a high quality DDGS product.

All diets, shown in Table 2, were formulated on a true ileal digestible (TID) lysine basis. The diets were formulated to contain 0.83, 0.70, and 0.58% TID lysine during the three phases with diet changes made at 133 and 200 lb body weight, respectively. The DDGS replaced corn and soybean meal, and up to 0.22% L-lysine-HCl (0.17% L-lysine) and 0.04% L-tryptophan were added to maintain constant TID levels of these amino acids in each phase. The calcium and digestible phosphorus levels were held constant during each phase. Because of the high level of digestible phosphorus in DDGS, no supplemental phosphorus was needed in the diets containing the highest level of DDGS. All diets were fortified with salt, vitamins, and trace minerals to meet or exceed NRC (1998) standards, and tylosin was included in all diets. The diets were analyzed for crude protein and fat at our station and for fatty acid composition and iodine number at the University of Georgia.

Pigs were housed in 6 x 10 ft pens with concrete slatted floors in an environmentally controlled unit at the University of Kentucky Swine Research Farm. The pigs were allotted to treatments from outcome groups based on initial weight and sex in a randomized complete block design. There were three replications (two pens of barrows and one pen of gilts) with five pigs per pen. Pigs were weighed and feed intake was determined at 2-week intervals and at weekly intervals toward the end of the experiment. Diets and water were provided on an ad libitum basis. The growth performance aspect of the experiment was terminated on a replication basis when the pigs in the control pen (Diet 1) of a given replication reached an average weight of 265 lb. Any pens within a replication that did not reach the targeted weight were continued on their respective diets until they reached the target weigh of 265 lb.

When the pens came off test, all pigs were given a tattoo and transported to the University of Kentucky meats laboratory. They were slaughtered using humane procedures. Carcass hot weight, 10^{th} rib backfat, and 10^{th} rib longissimus area were measured, and percentage of fat-free lean in the carcass was calculated using the NPPC (2000) equation. A 10-g core of backfat was taken at the 10^{th} rib, and a 10-g core was also taken at the midpoint of the belly for determination of fatty acid composition. The backfat and belly fat core samples were packed in dry ice and sent by overnight mail to Dr. Michael Azain, University of Georgia, who determined the fatty acid profiles of fat from the inner and outer portions of the subcutaneous backfat and the belly fat.

Fatty Acid Profiles and Iodine Numbers. The fatty acid profiles of the subcutaneous adipose tissue, diets, and DDGS were determined by gas chromatography using a Shimadzu gas chromatograph (Model 14 A,Tokyo, Japan) with a flame ionization detector. Adipose tissue samples (50-100 mg) were transmethylated according to the method of Park and Goins (1994). Two mg of heptadecanoic acid (C 17:0) was added as an internal standard prior to 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 by multiplying the unsaturated fatty acids by factors and summing the result, as follows: iodine number = 16:1 (0.95) + 18:1 (0.86) + 18:2 (1.732) + 18:3 (2.616) + 20:1 (0.785) + 22:1 (0.723) (AOCS, 1998).

Belly Flex Measurements. Bellies were removed from the right side of each carcass and processed according to Institutional Meat Purchasing Specifications (IMPS #408; NAMP, 1997). Spareribs and related cartilage were removed, the bellies then squared (approximately 14 in. x 19 in.), and all remaining leaf fat was removed. The fresh bellies with the skin on were evaluated by an objective flex test performed by a method described by Rentfrow et al. (2003) by centering the squared belly, fat side down, on a 3 in. diameter polyvinyl chloride (PVC) pipe mounted perpendicular to a board marked with a 1 in. grid matrix. Lateral and vertical flex were determined from the degree of belly flex relative to the grid matrix. A lateral belly flex of zero meant the belly was completely parallel to the floor and completely stiff. A vertical belly flex of 6 meant that the belly flexed to a point where there was 6 in. between the ends of the squared belly and the center of the supporting PVC pipe. Thus, a lower lateral and a higher vertical flex would indicate a firmer belly. Upon completion of the belly flex test, each squared belly was divided into eight quadrants, and depth was measured in the center of each quadrant, then averaged.

Belly/Bacon Processing and Measurements. Uncooked bellies were skinned, transported to a commercial packing plant, and weighed before (green weight) and after injection (pumped weight). The bellies were pumped fat side down with typical commercial brine (water, salt, sugar, sodium phosphate, sodium erythorbate, and nitrite) at 112% of the belly green weight, then allowed to drain to 110% of the green weight. Bellies were hung by a bacon comb attached at the flank end and heat processed according to the plants commercial protocol. Following processing, bacon slabs were removed from the smokehouse, showered, drip dried, and then chilled overnight. The following morning, individual bacon slabs were weighed to determine smokehouse yield, then they were placed in a tempering cooler (-4º C) to facilitate optimal pressing and slicing. Full bacon slabs were pressed using a commercial bacon press, then sliced by a high-speed slicer at nine slices per inch. The bacon slices were then boxed for transport back to the University of Kentucky Meat Science Laboratory.

Slicing yield was determined by weighing the center portions of the bacon slab after the removal of comb marks and all incomplete slices. The remaining bacon slab, containing only commercially acceptable slices, was divided into five separate sections labeled A, B, C, D, and E (Mandigo, 1998; Rentfrow et al., 2003). The first two slices from the cranial end were removed from each section and evaluated for fracture analysis. Fracture analysis was evaluated by rolling the bacon slice over the forefinger, and a fracture was considered to be lateral or vertical cracks in the structural integrity of the bacon slice. Subjective fracture analysis was performed by dividing the slice into four quadrants along the length of the bacon slice and assigning a score for each quadrant. The scores were averaged for each slice. A score of 0 indicated that no visual cracks or shattering could be detected. The scoring increased in severity with 2, 3, 4, 5, and 6 with the highest score indicative of a "spider-web" consistency of shattering within the fat of the bacon slice.

Five bacon slices per slab, representing one slice from each section (described above); were cooked (golden brown; not crisp) to a target of 40% of the original bacon slice weight. Each slice was weighed before and after cooking to the nearest 0.1 g, and cooking loss was calculated as 100 x (raw weight – cooked weight)/raw weight. After cooking, slices were cooled for 10 minutes at room temperature on absorbent paper towels. Bacon slice length was measured to the nearest 0.1 in. cm before and after cooking. Bacon slice cooking shrink (length change) was calculated as 100 x (raw length – cooked length)/raw length. Subjective evaluation of cooked slice visual distortion was evaluated using a 5-point distortion scale where 1 represented a mostly flat slice, with severity of curling scores increasing to 2, 3, 4, and 5 where 5 indicated a slice that completely curled with no flat areas on the slice.

Fresh Sausage. Lean and fat trimmings were ground twice, analyzed for fat content, and mixed to target a fresh sausage that contained 30% fat. A typical bratwurst seasoning was added to the meat block, hand mixed, stuffed into 1 in. natural casings, and linked into 6 in. links. Two bratwurst sausage links were placed on styrofoam trays, over-wrapped with polyvinyl chloride (PVC), and stored at 4° C under cool florescent lighting (1,300 Lux) to evaluate shelf life stability. Objective and subjective color evaluations were taken at approximately the same time daily for 7 days. Objective color measurements (L*, a*, and b* values) were taken with a HunterLab Mini-scan XE Plus colorimeter standardized to black and white tiles over-wrapped with PVC at two locations on each link in the package for a total of four color measurements per package. Hue angle scores (degree of redness) and chroma scores (color intensity) were determined from the a* and b* color values.

Thiobarbituric acid reactive substances (TBARS) were evaluated on four packages of fresh bratwurst on days 0, 2, 3, 4, 5, 6, and 7. The TBARS were evaluated by a procedure described by Witte et al. (1970) and Schmedes and Holmer (1989). The TBARS measure represents the degree to which oxidation of the unsaturated fatty acids has occurred.

Sensory Panel Evaluation. An eight-member trained sensory panel was used to evaluate sensory characteristics of bacon, sausage, and boneless loin chops. Ten slices of bacon per belly (two per region as described above) were prepared for sensory evaluation by the cooking method previously described. The bacon was cut into 1 in. pieces and two pieces were served warm to each panel member. The panel used a 15 cm unstructured line scale to evaluate texture (0 = extremely tough, 15 = extremely tender or crumbly) and off-flavor (0 = no off-flavor, 15 = intense off-flavor). The evaluations of all 10 slices were averaged for each belly.

The fresh bratwurst sausage was steeped in water to an internal temperature of 71° C, each link was cut into 1 in. pieces, and one piece was served warm to each of the panel members. The panel used a 15 cm unstructured line scale to evaluate juiciness (0 = extremely dry, 15 = extremely juicy), texture (0 = soft and mushy, 15 = hard and chewy), and off-flavor (0 = no off-flavor; 15 = intense off-flavor).

A 1 in. chop was removed from the right longissimus muscle of each carcass posterior of the 10^{th} and 11^{th} rib separation for sensory panel evaluation. The chops were cooked in a convection oven to an internal temperature of 70° C, cut into ½ x ½ x 1 in. cubes, and two cubes served warm to each panel member. A 15 cm unstructured line scale was used by the panel to evaluate juiciness (0 = extremely dry, 15 = extremely juicy), tenderness (0 = extremely tough, 15 = extremely tender), and off-flavor intensity (0 = no off-flavor, 15 = intense off-flavor) under red lighting to mask color.

Statistical Analysis of the Data. All of the data were subjected to statistical analysis using the GLM procedure of SAS with pen considered the experimental unit. Responses were partitioned into linear and nonlinear trends. An alpha level of 5% was considered statistically significant and a 10% level was considered as a trend. Probability levels greater than 10% were considered not statistically significant and are shown as a dash in the tables.

Results and Discussion:

Table 3 shows a summary of the performance of the pigs fed the four experimental diets. Growth rate during Phase I of the study tended to be reduced slightly in pigs fed the two higher levels of DDGS, but this difference was not significant. During Phase III, pigs fed the three levels of DDGS tended to gain faster than controls, but the differences were not significant. Over the entire experiment, growth rate was not affected by feeding the various levels of DDGS. Daily feed intake was not significantly affected by DDGS level but tended to be highest in pigs fed the highest level of DDGS. The amount of feed required per unit of gain over the entire experiment increased linearly ($P < 0.02$) with increasing level of DDGS in the diet; this trend was also evident during Phase II and III ($P < 0.10$ and $P < 0.08$, respectively). These data indicate that high levels of DDGS can be fed to growing pigs without having much effect on growth rate provided the diets are properly formulated on a TID lysine basis and with supplemental amino acids so that the dietary protein level is not excessive. However about 7% more feed was required per unit of gain (feed/gain of 2.86 vs. 2.68) when pigs were fed the highest level of DDGS compared with controls.

A summary of the carcass traits is shown in Table 4. Carcass yield (dressing percent) was not significantly affected by feeding the higher levels of DDGS. Pigs fed the three levels of DDGS had less backfat (not significant) and larger loin eye areas ($P < 0.05$) than those fed the corn-soybean meal diet without DDGS.

Carcass fat-free lean percentage increased numerically when DDGS was included in the diet, but the trend was not significant.

Belly flex measurements, also shown in Table 4, were significantly affected by DDGS level in the diet. Lateral flex measurements decreased linearly ($P < 0.01$) and vertical flex increased linearly ($P < 0.03$) with increasing level of DDGS in the diet. Both of these measures indicated that bellies became softer and more flexible as level of DDGS increased in the diet.

The fatty acid composition (expressed as a percentage of the total fatty acids) of the extracted fat from the backfat and belly is shown in Table 5. The data show large and significant linear trends ($P < 0.001$) resulting from increasing the level of DDGS in the diet. The total polyunsaturated fatty acids increased from 14.4% in controls to 26.8% in outer backfat tissue and from 15.0% to 27.1% in inner backfat tissue of pigs fed the highest level of DDGS. The opposite trend occurred with the saturated and monounsaturated fatty acids. These same trends occurred in the belly fat. The higher percentage of polyunsaturated fatty acids and lower percentages of saturated and monounsaturated fatty acids in diets containing DDGS are indicative of a softer carcass.

The iodine values calculated from the fatty acids in the extracted fat increased from 63.4 and 65.1 in outer and inner backfat of the control pigs to 79.1 and 80.8, respectively, in backfat of pigs fed the highest level of DDGS. The response in iodine value was linear ($P < 0.001$). Similar trends occurred in the fat from the bellies. These responses, again, are indicative of softer fat in pigs fed increasing amounts of DDGS.

Table 6 shows the data from the bacon slabs and slices. Surprisingly, shatter scores of the fresh bacon slices improved linearly ($P < 0.001$) with increasing level of DDGS in the diet. This means that the quality of the uncooked bacon slices improved as the degree of belly fat unsaturation increased. Cooking shrink and distortion scores were not negatively affected by the increased softness of the bellies. According to the taste panel, texture of the cooked bacon slices tended to be slightly less tender with slightly more off-flavor in the high DDGS treatment group, but the differences were slight and not significant, and all were well within the acceptable range.

The color scores of the bratwurst sausages are shown in Table 7. Color scores varied some from day to day and among treatment groups, but most of the changes did not follow a consistent pattern. However, on day 5, the L* (degree of lightness), a* (degree of redness), and b* (degree of yellowness) scores became progressively lower as the amount of unsaturation of the fat increased. This means that the samples with more unsaturated fat were losing some of their color by day 5, and the color was becoming less vivid ($P < 0.001$) according to chroma scores. . However, by day 7, no treatment differences were noted.

Table 8 shows TBARS and taste panel scores of the bratwurst sausages. TBARS scores on day 7 increased linearly ($P < 0.02$) with increasing DDGS level. Also, the increase is TBARS scores on day 7 compared with the initial scores on day 0 was linearly ($P < 0.005$) affected by level of DDGS. These changes indicate that more oxidative products were being produced by the more highly unsaturated fat in the 45% DDGS group. However, these sausages had only slightly higher off-flavor scores that were not significant. Sausages prepared from carcasses that contained more unsaturated fat were more tender ($P < 0.004$) and juicy (linear, $P < 0.04$).

Taste panels were unable to detect any differences in tenderness, juiciness, or off-flavor in loin chops (Table 9) from pigs fed the various levels of DDGS.

Summary:

The results of this study showed that rather high levels of DDGS (up to 45% DDGS in the diet) can be fed to growing-finishing pigs without having much of an effect on growth rate; however, the amount of feed required per unit of gain was increased with increasing amounts of DDGS in the diet. Carcass leanness was not greatly affected by level of DDGS; however, the high levels of DDGS in the diet resulted in higher proportions of unsaturated fatty acids in the body fat, higher iodine values in the backfat and belly fat, and softer, more flexible bellies. These responses were linearly ($P < 0.05$) related to the amount of DDGS in the diet. Regardless of the changes in fat composition, the slicing efficiency of cured bacon slabs, quality measures of fresh sliced bacon, and eating quality of bacon, bratwurst sausage, and loin chops did not seem to be negatively affected by feeding 30 to 45% DDGS to growing-finishing pigs.

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Table 1. Composition of the DDGS used in the study

	%
Dry matter	88.9
Crude protein	26.3
Crude fat	9.7
Acid detergent fiber	14.0
Neutral detergent fiber	34.6
Crude fiber	6.5
Ash	5.1
Calcium	0.03
Phosphorus	0.86
Sulfur	0.68
Lysine	0.96
Tryptophan	0.18
Threonine	0.99
Methionine	0.50
Cysteine	0.50
Valine	1.35
Isoleucine	1.01

Table 2. Composition of diets (%, as fed basis)

	---------- Phase I -----------				-----------Phase II --------				----------Phase III ---------			
Diet:	1	2	3	4	1	2	3	4	1	2	3	4
Corn	72.48	61.94	51.40	40.87	77.91	67.56	57.21	46.86	82.71	72.10	61.50	50.89
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	--	15.00	30.00	45.00	--	15.00	30.00	45.00	--	15.00	30.00	45.00
L-lysine-HCl	--	0.067	0.133	0.200	--	0.073	0.147	0.220	--	0.065	0.130	0.195
DL-tryptophan	--	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	1.40	0.58	0.85	1.13	1.40
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
Vitamins, trace minerals	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	0.05	0.05	0.05	0.05	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis												
Protein, %	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 lysine, %	0.95	0.98	1.02	1.06	0.80	0.84	0.87	0.91	0.67	0.70	0.74	0.78
TID lysine, %[1]	0.83	0.83	0.83	0.83	0.70	0.70	0.70	0.70	0.58	0.58	0.58	0.58
TID tryptophan, %	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	0.60	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

[1]The true ileal digestible (TID) lysine requirement (NRC, 1998) for pigs at the midpoint of the three phases is 0.80, 0.67, and 0.62%, respectively.

Table 3. Performance traits of pigs fed four levels of DDGS during three phases[1]

Item	DDGS, % 0	15	30	45	SE	Probability Linear	Quad
Body weight, lb							
Initial	75.8	75.8	75.9	75.4	0.19	-	-
End of Phase I	137.1	137.1	133.1	133.5	2.20	-	-
End of Phase II	204.6	203.1	197.7	200.8	3.89	-	-
End of Phase III	259.4	260.0	254.9	258.5	6.11	-	-
End of Phase III (constant wt)	267.8	266.0	260.5	265.1	2.60	-	-
Phase I							
Avg daily gain, lb	2.19	2.20	2.05	2.08	0.07	-	-
Avg daily feed intake, lb	4.83	4.81	4.57	4.78	0.11	-	-
Feed/gain	2.20	2.19	2.23	2.30	0.05	-	-
Phase II							
Avg daily gain, lb	2.43	2.37	2.31	2.41	0.18	-	-
Avg daily feed intake, lb	6.65	6.56	6.52	7.01	0.20	-	-
Feed/gain	2.74	2.77	2.82	2.91	0.07	0.10	-
Phase III							
Avg daily gain, lb	2.33	2.39	2.39	2.41	0.10	-	-
Avg daily feed intake, lb	7.36	7.74	7.55	8.11	0.27	-	-
Feed/gain	3.17	3.25	3.15	3.36	0.05	0.08	-
Final, all phases							
Avg daily gain, lb	2.32	2.32	2.25	2.29	0.08	-	-
Avg daily feed intake, lb	6.22	6.30	6.15	6.56	0.17	-	-
Feed/gain	2.68	2.72	2.74	2.86	0.04	0.02	-

[1]Data based on three replications of five pigs per pen.

Table 4. Carcass traits and belly firmness of pigs fed four levels of DDGS[1]

	DDGS, %					Probability	
Item	0	15	30	45	SE	Linear	Quad
Kill wt, lb	267.8	267.3	263.0	267.5	2.88	-	-
Carcass wt, lb	196.6	195.0	191.0	194.5	2.31	-	-
Dress, %	73.4	73.0	72.6	72.7	0.32	-	-
Backfat, 10th rib, in.	1.02	0.95	0.92	0.97	0.05	-	-
Loin eye area, sq. in.	7.36	7.92	7.68	7.68	0.11	-	0.05
Carcass fat-free lean, %	50.7	52.4	52.5	51.8	0.72	-	-
Belly flex[2]							
Lateral, in.	4.06	2.81	2.37	1.83	0.45	0.01	-
Vertical, in.	10.90	11.51	11.73	12.13	0.30	0.03	-

[1]Data from three replications of five pigs per pen.

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

Table 5. Fatty acid composition and iodine value of fat in backfat tissue of pigs fed four levels of DDGS[1]

	DDGS, %					Probability	
Item	0	15	30	45	SE	Linear	Quad
Fat composition of the outer backfat							
Fatty acids, % of total							
Saturated	40.6	37.1	35.1	34.0	0.73	0.001	-
Monounsaturated	45.0	44.9	41.8	39.2	0.89	0.002	-
Polyunsaturated	14.4	18.1	23.2	26.8	0.82	0.001	-
Linoleic acid	13.5	17.0	21.8	25.3	0.81	0.001	-
Iodine value of lipid[2]	63.4	69.5	75.2	79.1	1.10	0.001	-
Fat composition of the inner backfat							
Fatty acids, % of total							
Saturated	39.7	38.5	35.5	32.6	0.87	0.001	-
Monounsaturated	45.3	43.6	39.9	40.3	0.96	0.005	-
Polyunsaturated	15.0	17.9	24.7	27.1	1.17	0.001	-
Linoleic acid	14.2	16.9	23.7	25.8	1.13	0.001	-
Iodine value of lipid[2]	65.1	68.4	76.9	80.8	1.68	0.001	-
Fat composition of the belly fat							
Fatty acids, % of total							
Saturated	37.4	35.6	33.5	31.6	0.58	0.001	-
Monounsaturated	49.2	47.5	44.1	43.6	0.56	0.001	-
Polyunsaturated	13.4	17.0	22.4	24.8	0.65	0.001	-
Linoleic acid	12.4	15.8	20.9	23.3	0.65	0.001	-
Iodine value of lipid	65.4	69.7	75.8	79.5	1.03	0.001	-

[1]Data from three replications of five pigs per pen.

[2]An iodine value of 70 or less is desirable. A score of 73-74 is generally considered to be the maximum that is acceptable by packers.

Table 6. Bacon traits and taste panel evaluation of bacon from carcasses of pigs fed four levels of DDGS[1]

	DDGS, %					Probability	
Item	0	15	30	45	SE	Linear	Quad
Belly weights							
Green weight, kg	4.79	5.05	4.67	4.69	0.18	-	-
Pumped weight, kg	5.31	5.53	5.08	5.02	0.21	-	-
Smoked weight, kg	4.55	4.85	4.36	4.41	0.21	-	-
Sliced weight, kg	3.37	3.54	3.39	3.29	0.33	-	-
Slicing yield, %	73.5	72.8	78.0	73.7	4.58	-	-
Bacon traits							
Shatter score of fresh bacon slices[2]	4.37	4.10	3.55	3.54	0.16	0.001	-
Cooking shrink, %	6.61	6.84	6.65	7.19	0.27	-	-
Distortion score of fried bacon[3]	2.68	2.46	2.51	2.56	0.16	-	-
Taste panel evaluation[4]							
Texture[5]	7.98	7.77	7.79	7.64	0.37	-	-
Off-flavor[6]	3.23	3.28	2.79	3.61	0.25	-	-

[1]Bellies from three replications of five pigs per pen.

[2]Fresh bacon slices were given scores of 0 to 6, with 0 representing no visual cracks or shattering and scores of 2, 3, 4, 5, and 6 representing increases in severity of shattering within the fat of the bacon slice. A score of 6 represented a "spider-web" consistency of shattering.

[3]Cooked bacon slices were scored using a 5-point scale where 1 represented a flat slice after cooking, with scores of 2, 3, 4, and 5 representing increased severity of curling scores. A score of 5 indicated a slice that completely curled with no flat areas on the slice.

[4]Taste panel evaluation was performed by an eight-member panel.

[5]Texture scores: 0 to 15 with 0 = extremely tough and 15 = extremely tender or crumbly.

[6]Off-flavor scores: 0 to 15 with 0 = no off-flavor and 15 = intense off-flavor.

Table 7. Color scores of bratwurst sausage from carcasses of pigs fed four levels of DDGS[1]

	DDGS, %					Probability	
Item	0	15	30	45	SE	Linear	Quad
L* color scores[2]							
Day 0	52.58	52.27	52.11	53.53	0.92	-	-
Day 3	48.63	49.66	47.68	50.52	1.29	-	-
Day 5	50.58	49.37	46.47	47.48	1.09	0.05	-
Day 7	50.10	50.04	50.70	51.15	1.28	-	-
Change, day 0 to 7	-2.48	-2.22	-1.41	-2.38	1.87	-	-
a* color scores[3]							
Day 0	13.49	13.60	12.78	12.01	0.70	-	-
Day 3	12.40	12.19	12.88	11.56	0.41	-	-
Day 5	9.84	9.31	9.03	7.96	0.20	0.001	-
Day 7	8.75	8.73	8.94	8.30	0.34	-	-
Change, day 0 to 7	-4.74	-4.87	-3.84	-3.71	0.82	-	-
b* color scores[4]							
Day 0	19.13	18.67	17.40	17.43	0.61	0.06	-
Day 3	21.17	21.00	22.33	21.04	1.00	-	-
Day 5	18.17	17.34	15.59	14.80	0.51	0.002	-
Day 7	17.83	17.62	17.10	17.12	0.57	-	-
Change, day 0 to 7	-1.29	-1.05	-0.29	-0.31	0.31	0.04	-
Hue angle score[5]							
Day 0	55.11	54.18	53.88	55.63	0.77	-	-
Day 3	59.84	59.96	60.23	61.42	0.83	-	-
Day 5	61.76	61.90	60.11	61.95	0.50	-	-
Day 7	63.99	63.83	62.63	64.37	1.08	-	-
Change, day 0 to 7	8.88	9.66	8.75	8.74	1.51	-	-
Chroma score[6]							
Day 0	23.41	23.10	21.58	21.17	0.87	0.08	-
Day 3	24.54	24.29	25.78	24.01	1.02	-	-
Day 5	20.67	19.69	18.02	16.81	0.53	0.001	-
Day 7	19.87	19.67	19.30	19.03	0.55	-	-
Change, day 0 to 7	-3.54	-3.43	-2.28	-2.13	0.58	0.08	-

[1]Based on three replications of five pigs per pen.

[2]L* score: degree of lightness with 0 = black and 100 = white.

[3]a* score: degree of redness with negative values = green and positive values = red.

[4]b* score: degree of yellowness with negative values = blue and positive values = yellow.

[5]Hue angle is calculated as arctangent (b*/a* x 57.5) and represents degree of redness with 0 = red and 60 = yellow.

[6]Chroma is calculated as the square root of ($a^{*2} + b^{*2}$) and represents how vivid the color appears. A higher number represents a more vivid color.

Table 8. Thiobarbituric acid reactive substance (TBARS) and taste panel evaluation of bratwurst sausage from carcasses of pigs fed four levels of DDGS[1]

	DDGS, %					Probability	
Item	0	15	30	45	SE	Linear	Quad
TBARS scores[2]							
Day 0	0.200	0.198	0.190	0.186	0.014	-	-
Day 3	0.204	0.192	0.225	0.200	0.025	-	-
Day 5	0.217	0.190	0.176	0.165	0.020	0.10	-
Day 7	0.209	0.191	0.239	0.278	0.019	0.02	-
Change, d 0 to 7	0.009	-0.007	0.049	0.092	0.016	0.005	-
Taste panel evaluation							
Texture[3]	8.46	6.97	7.38	6.52	0.27	0.004	-
Juiciness[4]	6.70	7.50	7.38	8.19	0.37	0.04	-
Off-flavor[5]	2.61	2.76	2.56	2.82	0.25	-	-

[1]Based on three replications of five pigs per pen. The taste panel consisted of eight members.

[2]TBARS absorbance scores represent the amount of fatty acid oxidation that has occurred. A higher score represents greater oxidation of the fat due to presence of more unsaturated fatty acids; this may reduce shelf life and increase the chances of off-flavor.

[3]Texture scores: 0 to 15 with 0 = soft and mushy, 15 = hard and chewy.

[4]Juiciness scores: 0 to 15 with 0 = extremely dry, 15 = extremely juicy.

[5]Off-flavor scores: 0 to 15 with 0 = no off-flavor, 15 = intense off-flavor

Table 9. Taste panel evaluation of loin chops from carcasses of pigs fed four levels of DDGS[1]

	DDGS, %					Probability	
Item	0	15	30	45	SE	Linear	Quad
Taste panel evaluation							
Tenderness[2]	8.34	7.89	8.13	8.63	0.37	-	-
Juiciness[3]	5.09	5.20	5.06	5.68	0.64	-	-
Off-flavor[4]	6.62	5.55	5.50	5.46	0.49	-	-

[1]Based on three replications of five pigs per pen. The taste panel consisted of eight members.

[2]Tenderness scores: 0 to 15 with 0 = extremely tough, 15 = extremely tender.

[3]Juiciness scores: 0 to 15 with 0 = extremely dry, 15 = extremely juicy.

[4]Off-flavor scores: 0 to 15 with 0 = no off-flavor, 15 = intense off-flavor