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Effects of corn distillers dried grains with solubles on quality traits of pork[1,2,3]

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ABSTRACT: The high cost of feed grains has led swine producers to seek alternative feedstuffs, such as distillers dried grains with solubles (DDGS). However, little is known about the effects of high levels of DDGS in swine diets on pork quality. The objective of this study was to evaluate belly processing and bacon, sausage, and loin quality of pigs fed high levels of DDGS. Sixty pigs averaging 34 kg BW were fed fortified corn-soybean meal diets containing 0%, 15%, 30%, or 45% DDGS. At 120 kg BW, the pigs were humanely harvested and bellies, loins, and shoulders were removed from the left side of each carcass. Flex tests of bellies indicated that they became softer (linear, $P < 0.03$) as DDGS levels increased. The PUFA in backfat and belly fat increased linearly ($P < 0.005$), as did iodine values with increasing 0DDGS in the diet. Bellies were pumped to target 12% brine retention, cooked, and sliced at a commercial facility. Slicing yield was not affected by DDGS level fed. Fresh bacon slices were scored 1 to 6 with 1 representing no visible cracks in the fat and 6 representing a spider web-like shattering of the fat. Shatter scores decreased (linear, $P < 0.001$) with increasing dietary DDGS. Bratwurst-style sausage was produced by combining ground Boston butts and picnics to target 30% fat, blended with commercial seasonings, and stuffed into natural casings. Loose sausage was placed on trays, overwrapped with polyvinyl chloride wrap, and stored under constant, cool white florescent lighting (1,300 lx) at 4°C. Objective color values (L^*, a^*, and b^*) were taken on loose-packaged sausage mix at 6 locations at the same time daily for 7 d. Sausage was also sampled for thiobarbituric acid reactive substances (TBARS) at the same time daily on d 0, 3, 5, and 7. Color scores of sausage were not consistently affected by DDGS level in the diet and the changes were slight. The TBARS in sausage from pigs fed the 30% and 45% DDGS diets increased to a greater extent from d 0 to 7 than in those fed the control or 15% DDGS diets. An 8-member, trained panel evaluated the sensory attributes of bacon slices, sausage, and loin chops. The DDGS resulted in a softer texture ($P < 0.004$) and increased juiciness ($P < 0.04$) in sausages, but no differences in sensory scores were found in bacon slices or loin chops. The results indicate that the softer bellies, greater concentrations of PUFA in carcass fat, and greater iodine values associated with feeding increased DDGS did not negatively affect slicing yield of cured bellies, quality of fresh bacon slices, or eating quality of bacon, sausage, or loin chops.

Key words: bacon, bratwurst sausage, distillers dried grains with solubles, loins, pigs, pork quality

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INTRODUCTION

Many research studies have recently been conducted to evaluate distillers dried grains with solubles (**DDGS**) as a coproduct in swine diets. Stein and Shurson (2009) reported that adding up to 30% DDGS to the diet caused no negative effects in performance of growing-finishing pigs. Recently, a large, collaborative study conducted at 9 universities indicated that up to 45% DDGS could be added to swine diets with little effect on performance, but it caused softer bellies with greater percentages of PUFA (Cromwell et al., 2011).

[1]Journal paper no. 11-07-077 of the Kentucky Agricultural Experiment Station.

[2]The pigs in this study were from the University of Kentucky contribution to a larger study conducted by the North-Central Coordinating Committee on Swine Nutrition (NCCC-42) and published as J. Anim. Sci. 89:2801–2811 (2011).

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The quality of bacon and processed pork is based largely on the quality of the fat in those products. Fatty acid profiles and iodine values have been used to predict belly quality before processing into bacon. Adding unsaturated fat to swine diets alters fatty acid profiles, particularly increasing the percentage of PUFA, and produces softer bellies (Rentfrow et al., 2003; Larsen et al., 2009). Because DDGS contains ~10% fat, it is logical to believe it could affect fatty acid profiles and fat quality of pork bellies. Wood et al. (2003) suggested that having a concentration of ≥3% of linolenic acid can have negative effects on the shelf life and flavor of pork products. The National Pork Producers Council (2000) stated that pork fat should possess <15% PUFA and >15% stearic acid to be considered good quality. Thus, pork fat quality is important to both fresh pork products, as well as further processed ones.

The effects of DDGS in swine diets on quality attributes of fresh and processed pork products is an important factor to consider. Fresh pork makes up 3.5% and processed meat products account for 64% of the retail meat case (Wright et al., 2005); bacon is one of the most important of these, comprising close to 8% of the retail case. With the high presence of bacon in the retail case and its prominent use in restaurants, research focusing on bacon and fat quality is crucial.

The objective of this study was to determine if the inclusion of increased amounts of DDGS to swine diets would alter fatty acid profiles enough to impact quality of fresh bellies and processed pork, and eating quality of bacon, sausage, and loin chops.

MATERIALS AND METHODS

All procedures in our study were approved by the University of Kentucky's Institutional Animal Care and Use Committee.

This experiment was part of a large, multistate study involving 9 experiment stations. That study assessed the effects of feeding 4 levels of DDGS (0%, 15%, 30%, and 45%) on pig performance, carcass traits, and belly firmness, but not meat quality or sensory traits. The multistate study consisted of 28 replications of 4 to 6 pigs per pen with each station contributing 2 to 4 replications; the University of Kentucky contributed 3 replications of 5 pigs (n = 15 pigs per treatment) to the multistate study. The procedures that were common to all stations are described in more detail in a previous paper (Cromwell et al., 2011).

Animals and Diets

Sixty crossbred pigs (Duroc-Hampshire males × Yorkshire-Landrace females), initially averaging 34 kg BW, were blocked by weight, sex, and ancestry, and randomly allotted to 4 dietary treatments consisting of a fortified, corn-soybean meal diet, containing either 0%, 15%, 30%, or 45% DDGS. The DDGS, which contained 9.4% crude fat and 26.3% CP, was supplied for our study (and for the other stations in the entire multistate study) by Archer Daniel Midland (Decatur, IL). In our study, there were 3 replicate pens (n = 15 per treatment), which included 2 pens of 5 barrows each and one pen of 5 gilts. The DDGS replaced corn and soybean meal, and AA were supplemented to maintain a consistent true ileal digestible lysine concentration across all treatments. Diets were fed in 3 phases. The composition of the diets was described in Cromwell et al. (2011). Pigs were transported to the University of Kentucky Meats Laboratory for humane harvest when the average pen weight reached 120 kg. Feed was available to the pigs until ~3 h before they were harvested.

Harvest and Carcass Composition

Pigs were weighed immediately before harvest and HCW were recorded to calculate dressing percentage [(HCW/BW) × 100)]. Following a 24-h chill (4°C), the 10th rib backfat and LM area were measured from the left side of each carcass for estimated percentage of carcass fat-free lean (National Pork Producers Council, 2000). In addition, the Boston butt (IMPS #406), shoulder picnic (IMPS #405), loin (IMPS #412), and belly (IMPS #408; squared at each end, teat line removed) were removed, according to Institutional Meat Purchasing Specifications (North American Meat Processors Association, 2010).

Belly/Bacon Quality Measurements

Spare ribs and related cartilage, and leaf fat were removed from the belly before being placed skin-side down on a 6.4-cm polyvinyl chloride (**PVC**) pipe mounted perpendicular to a 2.54-cm grid matrix and flex (vertical and horizontal) of the belly was measured. A firmer belly has a smaller numerical vertical flex and larger numerical lateral flex. Additionally, bellies were also measured for thickness in 8 locations from shoulder to flank end before being vacuum packaged, boxed, and then frozen (–22°C) until further analyses. Further description of the apparatus for obtaining flex measurements are in a previous paper (Cromwell et al., 2011).

Bellies were thawed at 4°C, skinned, boxed, and transported ~750 km to a commercial facility (Burgers Smokehouse, California, MO). The fresh bellies were weighed (green weight) and then injected (Mepsco, Chicago, IL), fat side down, with a proprietary brine that contained 14.5% salt. The brine was injected to ~112% of green weight, allowed to drain to ~110% of the green weight, and reweighed to determine pumped weight. Bacon combs were attached at the flank end and thermally processed, according to the protocol at the plant. Cooked bacon slabs were chilled overnight (4°C) and reweighed the next morning to determine smokehouse yield. Slabs were then pressed (Hoegger Model IP-420, Mudau-Schlossau, Germany) before individually sliced through a high-speed slicer at 9 slices per 2.54 cm. All end pieces and slices from each bacon slab were collected, boxed separately, and transported back to the University of Kentucky Meats Laboratory. All incomplete slices, comb marks, or any other slices determined to be defective were removed, and the remaining slices were weighed to determine the slice yield [100 × (slice wt/smoke wt)].

Bacon slices were divided into 5 equal sections after removal of incomplete slices from anterior to posterior end. The first 2 slices from the cranial end of each section were selected for shatter evaluation and 2 additional slices were removed for cook shrink and distortion evaluation. A trained evaluator determined shatter by rolling a raw bacon slice over the index finger to determine the amount of fracturing occurring in the fat at 4 locations along the length of the slice. A fracture (shatter) was considered as the lateral and vertical cracking in the fat. A score of 1 indicated no visual cracks and scoring increased in severity as 2, 3, 4, 5, and 6 (Rentfrow et al., 2003). A score of 6 implied a "spider-web" consistency of fracturing. Scores were averaged for each slice.

The following 2 slices from the cranial end of each section were weighed and measured for length, then cooked on a flat griddle at 157°C (determined by a surface thermometer; Raytek, Santa Cruz, CA) to target 40% of the original slice weight. Cooked slices were allowed to cool for 10 min on absorbent paper towels, then reweighed and length remeasured to determine actual cook loss and shrinkage. A 5-point subjective scale was used to evaluate cooking distortion; a score of 1 indicated a flat slice with no curling and distortion scores increased in severity as 2, 3, 4, and 5. A score of 5 indicated a severely curled bacon slice (Rentfrow et al., 2003).

Fatty Acid Profile and Iodine Value

A sample of backfat from the posterior end of the 10th rib and a sample of belly fat (ventral corner of the flank end) were removed and frozen (–22°C) until fatty acid analysis could be performed. After thawing, the fat cores were trimmed free of lean and skin, and separated into the outer layer and inner layer of fat. Fatty acid profiles were determined by gas chromatography, using a Shimadzu gas chromatograph (Model 14 A, Tokyo) with a flame ionization detector. Details on the procedure are described in Cromwell et al. (2011). The iodine value was calculated from the fatty acid profile, using an equation from the American Oil Chemists Society (AOCS, 1998): Iodine value = (16:1 × 0.95) + (18:1 × 0.86) + (18:2 × 1.732) + (18:3 × 2.616) + (20:1 × 0.785) + (22:1 × 0.723).

Sausage Formulation and Packaging

Bratwurst-style sausage was made from the Boston butt and shoulder picnic from each pig within each treatment. The 2 cuts were deboned and then ground separately, each twice through a 6.35-mm grinder plate. A 20-g random sample was removed for fat percentage analysis. Samples from Boston butts and picnic shoulders were homogenized before fat and moisture were determined on a 5-g sample, using a microwave analyzer (Data Support Co., Model HFT 2000, Panorama City, CA). Based on fat percentage, Boston butts and picnics (from the same pig) were blended to target 30% fat in the sausage, using the Pearson Square Method. The sausage was then reanalyzed to ensure each sausage formulation contained 30% fat. A commercial blend of bratwurst seasoning was added to the ground sausage and hand mixed. Loose sausage mix (0.45 kg) was placed on a styrofoam tray and overwrapped with oxygen-permeable PVC (15,500 to 16,275 cm^3 O_2 · m^{-2} · 24 h^{-1} at 23°C, E-Z Wrap Crystal Clear Polyvinyl Chloride Wrapping Film; Koch Supplies, Kansas City, MO). The overwrapped, loose sausage mix was stored in a 4°C cooler under constant, cool, white florescent lighting (1,300 lx) for 7 d to determine shelf life stability. Objective color (*CIE L*, a*, b**) was evaluated through the PVC film on d 0, 2, 3, 4, 5, 6, and 7, at approximately the same time daily at 6 locations (small marks were placed on the package to ensure consistency) on the overwrapped sausage. A HunterLab MiniScan XE Plus colorimeter (HunterLab Associates, Reston, VA) with illuminant D65, 2.54-cm-diam. aperture, and 10º standard observer, standardized to black and white tiles overwrapped with PVC was used. Spectral reflectance was determined every 10 nm over the 400 to 700 nm range. The 6 values for each sausage package were averaged. Hue angle [atan^{-1} (57.5 × b^*/a^*)] was calculated to determine the degree of redness and chroma scores [sq. root ($a^{*2} + b^{*2}$)] were determined to assess the color intensity of the sausage (AMSA, 1991). The remaining sausage mix was stuffed into 2.54-cm-diam. natural casings and made into 15.24 cm links for sensory evaluation. Links were vacuum packaged and stored (4°C) until further analysis.

Thiobarbituric Acid Reactive Substances

Samples were taken from an additional package of PVC-overwrapped, loose bratwurst sausages stored at 4°C under cool florescent lighting (1,300 lx) on d 0, 3, 5, and 7, for thiobarbituric acid reactive substances (**TBARS**) analysis. Secondary products of lipid oxidation were measured, using the thiobarbituric acid assay (Yin et al., 1993). Duplicate 5-g samples were blended with 11% trichloroacetic acid solution and then filtered. One milliliter of filtrate was added to 1 mL of a 20-mM thiobarbituric acid solution and incubated in a water bath at 25ºC for 20 h. The absorbance of samples was measured with a spectrophotometer (Shimadzu UV-2401 PC spectrophotometer, Shimadzu Inc., Columbia, MD) at 532 nm and reported as TBARS.

Sensory Evaluation

An 8-member, trained sensory panel consisting of University of Kentucky faculty, staff, and graduate students was used to evaluate the tenderness and off flavor of bacon slices, texture, juiciness, and off flavor of bratwurst style sausage, and tenderness, juiciness, and off flavor of loin chops. Two slices from the center of each bacon belly were selected for the sensory panel, cooked on a flat griddle at 157°C (measured with Raytek surface thermometer) to target 40% of the original weight, and a 2.54-cm piece was served warm to the panelists under red lighting. A cup of water was provided between samples. Panelists evaluated tenderness (0 = extremely tough, 15 = extremely tender or crumbly) and off flavor (0 = no off flavor, 15 = intense off flavor) on a 15-cm unstructured line scale (AMSA, 1995).

Bratwurst sausage links were steeped in water and cooked to an internal temperature of 7°C. Internal temperature was monitored with a scanning thermocouple, using copper-constantin thermocouple wires (ThermoWorks, Inc. Alpine, UT). Links were sliced into 2.54-cm pieces and 1 piece was served warm to each panelist under red lighting, with a cup of water provided between each sample. Using a 15-cm unstructured line scale, panelists evaluated texture (0 = soft and mushy, 15 = hard and chewy), juiciness (0 = extremely dry, 15 = extremely juicy), and off flavor (0 = no off flavor, 15 = intense off flavor) of the sausage samples (AMSA, 1995).

A 2.54-cm loin chop was removed from the anterior portion of the longissimus lumborum muscle at the 10th and 11th rib separation. Loin chops were cooked on a clam-shell grill to an internal temperature of 70°C. Internal temperature was monitored with a scanning thermocouple, using copper-constantin thermocouple wires (ThermoWorks, Inc., Lindon, UT). Chops were then sliced into 1.3-cm cubes and 2 cubes were served warm to each panelist under red lighting, with a cup of water provided between each sample. Panelists were asked to evaluate tenderness (0 = extremely tough, 15 = extremely tender), juiciness (extremely dry, 15 = extremely juicy), and off flavor (0 = no off flavor, 15 = intense off flavor) on a 15-cm unstructured line scale (AMSA, 1995). All sensory evaluations were approved by the University of Kentucky Internal Review Board.

Table 1. Carcass traits and belly firmness of pigs fed 4 levels of distillers dried grains with solubles (DDGS)[1]

Item	DDGS, %				SE	*P*-value	
	0	15	30	45		Linear	Quadratic
BW, kg	121.6	121.3	119.4	121.4	1.31	0.70	0.42
Carcass traits							
HCW, kg	89.2	88.5	86.7	88.3	1.05	0.36	0.32
Dressing percent	73.4	73.0	72.6	72.7	0.32	0.15	0.46
Backfat, 10th rib, cm	2.59	2.42	2.35	2.47	0.13	0.48	0.30
LM area, sq. cm	47.5	51.1	49.5	49.5	0.73	0.22	0.05
Fat-free lean, %[2]	50.7	52.4	52.5	51.8	0.72	0.35	0.16
Belly traits							
Lateral flex, cm^3	10.32	7.14	6.01	4.64	1.13	0.02	0.46
Vertical flex, cm^3	27.68	29.23	29.80	30.82	0.77	0.03	0.74
Thickness, cm^4	3.41	3.73	3.18	3.20	0.28	0.39	0.62

[1]Means based on 3 replications of 5 pigs per pen (n = 15 per treatment).

[2]Calculated according to the NPPC (2000) equation adapted to metric: 100 × {[3.899 + (0.464 × HCW, kg) – (3.914 × 10th rib backfat, cm) + (0.211 × LM area, cm^2)]/(HCW, kg)}.

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

[4] Mean of 8 measures of belly thickness.

Statistical Analysis

In analysis of the data, pen was considered the experimental unit. Data were analyzed as a randomized complete block design (Steel et al., 1997) and subjected to the GLM procedure (SAS Inst, Inc., Cary, NC). Data for the objective color measurements (L^*, a^*, b^*) and TBARS were also analyzed by the MIXED procedure of SAS. Differences among treatment means were partitioned with orthogonal polynomials into linear, quadratic, and cubic trends. In the tables, *P*-values for cubic effects of treatments were not significant and are not reported. An alpha level of 5% was used to determine statistical significance.

RESULTS AND DISCUSSION

Carcass Characteristics and Belly Flex

Carcass dressing percent (Table 1) tended to be slightly less for pigs fed 30% and 45% DDGS, compared with the pigs fed 0% or 15% DDGS, but the differences were not significant. Some have reported reduced carcass yield with feeding DDGS (Stein and Shurson, 2009) and others have not (Leick et al., 2010). Backfat tended to be less (not significant) in pigs fed DDGS, which is similar to results of the larger study involving 9 stations (Cromwell et al., 2011). The LM area increased quadratically ($P < 0.05$) as DDGS in the diet increased, which is opposite of what was found in the larger study. These changes resulted in a numerical increase in estimated carcass, fat-free, lean percentage with increasing DDGS level. The increase in fat-free lean with increasing levels of DDGS in the larger study was linear (Cromwell et al., 2011).

Table 2. Fatty acid composition in lipid of inner and outer backfat and belly tissue of pigs fed 4 levels of distillers dried grains with solubles (DDGS)[1]

Item	DDGS, % 0	15	30	45	SE	P-value Linear	Quadratic
Fatty acids in inner backfat, % of total							
C14:0	1.10	1.04	1.03	0.95	0.035	0.03	0.79
C16:0	24.57	24.46	23.27	21.93	0.671	0.03	0.39
C16:1	2.99	3.03	2.63	2.34	0.160	0.02	0.34
C18:0	13.98	12.90	11.12	9.63	0.339	0.001	0.57
C18:1	41.85	40.03	36.97	37.44	1.015	0.02	0.30
C18:2	14.19	16.91	23.65	25.76	1.126	0.001	0.80
C18:3	0.52	0.54	0.54	0.53	0.089	0.95	0.86
C20:0	0.05	0.08	0.04	0.08	0.015	0.53	0.61
C20:1	0.48	0.52	0.29	0.50	0.061	0.56	0.21
C20:2	0.23	0.42	0.38	0.73	0.055	0.001	0.21
C20:4	0.04	0.07	0.08	0.10	0.015	0.03	0.87
Fatty acids in outer backfat, % of total							
C14:0	1.13	1.07	1.00	0.92	0.041	0.01	0.66
C16:0	26.07	23.67	22.74	22.16	0.460	0.001	0.10
C16:1	2.55	2.87	2.68	2.03	0.253	0.18	0.11
C18:0	13.33	12.23	11.23	10.85	0.354	0.01	0.35
C18:1	41.91	41.46	38.47	36.60	0.805	0.01	0.42
C18:2	13.49	17.02	21.81	25.33	0.809	0.001	0.99
C18:3	0.43	0.47	0.52	0.54	0.021	0.01	0.63
C20:0	0.12	0.10	0.11	0.10	0.018	0.57	0.75
C20:1	0.54	0.57	0.61	0.52	0.064	0.97	0.37
C20:2	0.34	0.47	0.68	0.80	0.033	0.001	0.91
C20:4	0.09	0.08	0.15	0.16	0.010	0.001	0.61
Fatty acids in belly fat, % of total							
C14:0	1.23	1.19	1.10	1.02	0.030	0.01	0.59
C16:0	24.42	23.44	22.09	21.05	0.298	0.001	0.92
C16:1	2.83	2.81	2.40	2.25	0.153	0.03	0.71
C18:0	11.64	10.84	10.24	9.49	0.373	0.01	0.95
C18:1	45.76	44.01	41.04	40.81	0.600	0.001	0.25
C18:2	12.42	15.80	20.94	23.33	0.652	0.001	0.48
C18:3	0.50	0.49	0.56	0.56	0.018	0.03	0.82
C20:0	0.07	0.12	0.08	0.03	0.034	0.34	0.15
C20:1	0.65	0.65	0.64	0.57	0.058	0.40	0.57
C20:2	0.40	0.55	0.76	0.77	0.044	0.001	0.18
C20:4	0.09	0.12	0.15	0.12	0.020	0.17	0.24

[1]Means based on 3 replications of 5 pigs per pen (n = 15 per treatment).

Table 3. Fatty acid composition and iodine value of lipid in backfat and belly tissue of pigs fed 4 levels of distillers dried grains with solubles (DDGS)[1]

Item	DDGS, % 0	15	30	45	SE	P-value Linear	Quadratic
Fatty acids in inner backfat, % of total							
Saturated	39.7	38.5	35.5	32.6	0.87	0.001	0.38
Unsaturated	60.3	61.5	64.5	67.4	0.87	0.001	0.38
Monounsaturated	45.3	43.6	39.9	40.3	0.96	0.005	0.31
Polyunsaturated	15.0	17.9	24.7	27.1	1.17	0.001	0.84
Fatty acids in outer backfat, % of total							
Saturated	40.6	37.1	35.1	34.0	0.73	0.001	0.14
Unsaturated	59.4	62.9	64.9	66.0	0.73	0.001	0.14
Monounsaturated	45.0	44.9	41.8	39.2	0.89	0.002	0.21
Polyunsaturated	14.4	18.1	23.2	26.8	0.82	0.001	0.99
Fatty acids in belly fat, % of total							
Saturated	37.4	35.6	33.5	31.6	0.59	0.001	0.90
Unsaturated	62.6	64.4	66.5	68.4	0.59	0.001	0.90
Monounsaturated	49.2	47.5	44.1	43.6	0.56	0.001	0.28
Polyunsaturated	13.4	17.0	22.4	24.8	0.65	0.001	0.41
Iodine values in lipid[2]							
Inner backfat	65.1	68.4	76.9	80.8	1.68	0.001	0.85
Outer backfat	63.4	69.5	75.2	79.1	1.11	0.001	0.35
Belly fat	65.4	69.7	75.8	79.5	1.03	0.001	0.80

[1]Means based on 3 replications of 5 pigs per pen (n = 15 per treatment).

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

The feeding of increasing DDGS to pigs resulted in linear increases in vertical flex ($P < 0.03$) and linear decreases in lateral flex of bellies ($P < 0.02$), indicators of softer, more flexible bellies. Other researchers have reported softer bellies resulting from the inclusion of DDGS or other unsaturated fat sources in pig diets (Rentfrow et al., 2003; Widmer et al., 2008; Larsen et al., 2009; Xu et al., 2010b.

Fatty Acid Profile and Iodine Value

The effects of DDGS in the diet on fatty acid profiles and iodine values in inner and outer backfat and belly fat are shown in Tables 2 and 3. As DDGS in the diet increased, percentages of most SFA and MUFA in backfat and belly fat decreased linearly ($P < 0.03$ to $P < 0.001$), whereas percentage of PUFA, especially linoleic acid, increased linearly ($P < 0.001$). As a result of these changes in fatty acid concentrations, the iodine values in backfat and belly fat increased linearly ($P < 0.001$) with increasing dietary DDGS. The iodine values increased by 6.1, 11.8, and 15.4 units in outer backfat, by 3.3, 11.8, and 15.7 units in inner backfat, and by 4.3, 10.4, and 14.1 units in belly fat, as the DDGS level in the diet increased from 0 to 45%. Adding increased amounts of unsaturated fat to swine diets has been shown by others to increase PUFA and iodine value in pork (Miller et al., 1990; Engel et al., 2001; Rentfrow et al., 2003; Apple et al., 2009). Whitney et al. (2006) and Stein and Shurson (2009) also reported that increased dietary DDGS resulted in a linear increase in iodine values from samples taken from various locations throughout the carcass. Xu et al. (2010a) also found that iodine values significantly increased, particularly in belly fat, with increased dietary inclusion of DDGS. Since DDGS contains ~10% fat, most of which consists of relatively large amounts of PUFA, it is logical that an increase in PUFA and iodine values of pork fat would occur in swine fed increased DDGS.

The National Pork Producers Council (2000) suggested that good quality pork fat should contain no more than 15% PUFA and no less than 15% stearic acid. The only treatment in our study that had <15% PUFA in belly fat samples was the control diet with no DDGS. The National Pork Producers Council (2000) also recommended a maximum iodine value of 70, whereas Boyd et al. (1997) listed an iodine value of 74 as maximum for pigs fed a corn-soybean meal diet. In our study, the iodine values in the sampled fat stores of pigs fed 15% DDGS were all <70. A collaborative study by 9 universities indicated that 13% and 22% DDGS in the diet resulted in iodine values of 70 and 74, respectively (Cromwell et al., 2011).

Some researchers have reported correlations between PUFA and iodine values in soft bellies. Whitney et al. (2006) found that 14% of variation in belly firmness could be attributed to iodine value, whereas 33% was attributed to belly thickness. Averette Gatlin et al. (2005) suggested that even if fat samples had the same iodine value, they could differ structurally. Closer investigations of fatty acid profiles may prove to be a useful measurement for belly quality than relying on iodine values.

Bacon Quality Traits

Table 4 shows the belly weights before and after pumping with brine, and the weights after smoking and slicing. None of these weights were significantly influenced by dietary treatment. The percent uptake of brine decreased linearly ($P < 0.01$) as DDGS increased and was not related to belly thickness. The slicing yield of the smoked bellies was highly variable, ranging from 94% to 38% (data not shown), but the means among the 4 treatments, ranging from 72.8 to 78.0%, were not different ($P = 0.20$). The common belief that soft bellies with high-iodine values possess slicing integrity problems when commercial high-speed slicers are used and the blade fails to make clean, individual slices was not apparent in this study. In a subsequent experiment at our station involving 6 replications of pigs that were fed 0 or 45% DDGS, slicing yield also was not affected by iodine values of pork bellies (Ulery et al., 2010). Several have reported that adding CLA to the diet increases saturated fatty percentages and belly firmness (King et al., 2004; Larsen et al., 2009; White et al., 2009), but in the 2 latter studies, the firmer bellies did not improve bacon sliceability.

Shatter scores of fresh bacon slices (Table 4) were improved in the softer bellies (linear, $P < 0.001$). The results showed that fracturing of bacon fat, which we expected to be greater in the softer bellies, was actually decreased with increased DDGS in the diet. Shrink of bacon slices during cooking and distortion scores of fried bacon were not affected by dietary treatment. These results indicate that it is not appropriate to assume bellies with softer fat or greater PUFA percentages, or both are inferior in quality.

Other variables that were not negatively affected by the increased DDGS in the diet were bacon sensory attributes (Table 4). Across all treatments, tenderness was not negatively impacted and was within a suitable range for

Table 4. Bacon traits and sensory evaluation of bacon from carcasses of pigs fed 4 levels of distillers dried grains with solubles (DDGS)[1]

	DDGS, %					*P*-value	
Item	0	15	30	45	SE	Linear	Quadratic
Belly traits							
Green wt, kg	4.79	5.05	4.67	4.69	0.18	0.45	0.54
Pumped wt, kg	5.31	5.53	5.08	5.02	0.21	0.22	0.54
Brine retention, %	10.94	9.42	8.88	7.14	0.71	0.01	0.89
Smoked wt, kg	4.55	4.85	4.36	4.41	0.21	0.38	0.57
Sliced wt, kg	3.37	3.54	3.39	3.29	0.33	0.80	0.69
Slicing yield, %	73.5	72.8	78.0	73.7	4.58	0.79	0.71
Bacon traits							
Shatter score of fresh bacon slices[2]	4.37	4.10	3.55	3.54	0.16	0.01	0.43
Cooking shrink, %	6.61	6.84	6.65	7.19	0.27	0.26	0.59
Distortion score of fried bacon[3]	2.68	2.46	2.51	2.56	0.16	0.68	0.41
Sensory evaluation of bacon[4]							
Texture[5]	7.98	7.77	7.79	7.64	0.37	0.57	0.95
Off flavor[6]	3.23	3.28	2.79	3.61	0.25	0.59	0.17

[1]Bellies from 3 replications of 5 pigs per pen (n = 15 per treatment).

[2]Bacon slices were given scores of 1 to 6, with 1 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 and scores of 2, 3, 4, and 5 represented increased severity of curling. A score of 5 indicated a slice that completely curled with no flat areas on the slice.

[4]Sensory evaluation was performed by a trained, 8-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 5. Color scores and thiobarbituric acid reactive substance (TBARS) of bratwurst sausage from carcasses of pigs fed 4 levels of distillers dried grains with solubles (DDGS)[1]

	DDGS, %				
Item	0	15	30	45	Day mean
L^* color scores[2]					
d 0	52.6	52.3	52.1	53.5	52.6
d 2	47.6	46.2	40.9	45.9	45.2
d 3	48.6	49.7	47.7	50.5	49.1
d 4	47.9	48.0	46.9	49.5	48.1
d 5	50.6	49.4	46.5	47.5	48.5
d 6	49.8	49.9	50.1	52.1	50.5
d 7	50.1	50.1	50.7	51.1	50.5
Treatment mean	49.6	49.4	47.9	50.0	
a^* color scores[3]					
d 0	13.5	13.6	12.8	12.0	13.0
d 2	14.8	15.0	17.9	14.9	15.7
d 3	12.4	12.2	12.9	11.5	12.3
d 4	11.1	11.1	11.3	10.2	10.9
d 5	9.8	9.3	9.0	8.0	9.0
d 6	9.9	11.8	11.1	9.3	10.5
d 7	8.7	8.7	8.9	8.3	8.7
Treatment mean	11.5	11.7	12.0	10.6	
b^* color scores[4]					
d 0	19.2	18.7	17.4	17.4	18.2
d 2	23.8	24.4	28.7	26.3	25.8
d 3	21.2	21.0	22.3	21.0	21.4
d 4	20.0	20.4	20.3	19.7	20.0
d 5	18.2	17.3	15.6	14.8	16.5
d 6	18.9	18.3	18.8	18.2	18.6
d 7	17.8	17.6	17.1	17.1	17.4
Treatment mean	19.9	19.6	20.0	19.2	
Hue angle[5]					
d 0	55.1	54.2	53.9	55.6	54.7
d 2	58.2	58.4	58.2	60.5	58.9
d 3	59.8	60.0	60.2	61.4	60.4
d 4	61.1	61.3	61.0	62.7	61.5
d 5	61.8	61.9	60.1	62.0	61.4
d 6	62.5	58.0	59.9	63.3	60.9
d 7	64.0	63.8	62.6	64.4	63.7
Treatment mean	60.4	59.6	59.4	61.4	
Chroma[6]					
d 0	23.4	23.1	21.6	21.2	22.3
d 2	28.0	28.7	33.8	30.2	30.2
d 3	24.5	24.3	25.8	24.0	24.7
d 4	22.9	22.9	23.2	22.2	22.8
d 5	20.7	19.7	18.0	16.8	18.8
d 6	21.3	22.0	21.9	20.4	21.4
d 7	19.9	19.7	19.3	19.0	19.5
Treatment mean	23.0	22.9	23.4	22.0	
TBARS, mg/kg[7]					
d 0	0.99	0.98	0.94	0.92	0.96
d 3	1.01	0.95	1.12	0.99	1.02
d 5	1.08	0.94	0.87	0.82	0.92
d 7	1.04	0.94	1.19	1.38	1.14
Treatment mean	1.03	0.95	1.03	1.03	

[1]Means for each treatment on each day based on 3 replications of 5 pigs per pen (n = 15 per treatment).

[2]L^* score: degree of lightness with 0 = black and 100 = white. Effect of day ($P < 0.001$). SE = 0.97 for treatment and 0.92 for day.

[3]a^* score: degree of redness with negative values = green and positive values = red. Quadratic effect of treatment ($P < 0.01$) and effect of day ($P < 0.001$). SE = 0.32 for treatment and 0.40 for day.

[4]b^* score: degree of yellowness with negative values = blue and positive values = yellow. Effect of day ($P < 0.001$). SE = 0.46 for treatment and 0.55 for day.

[5]Hue angle is calculated as arctangent (b^*/a^*) × 57.5 and represents degree of redness with 0 = true red and 60 = true yellow. Quadratic effect of treatment ($P < 0.04$) and effect of day ($P < 0.001$). SE = 0.58 for treatment and 0.66 for day.

[6]Chroma is calculated as the square root of ($a^{*2} + b^{*2}$) and represents how vivid the color appears. A larger number represents a more vivid color. Effect of day ($P < 0.001$). SE = 0.51 for treatment and 0.63 for day.

[7]TBARS represents the amount of fatty acid oxidation that has occurred. A larger score represents greater oxidation of fat due to presence of more unsaturated fatty acids; this may reduce shelf life and increase chances of off flavor. Cubic effect of day ($P < 0.02$) and treatment × day interaction ($P < 0.06$). SE = 0.08 for treatment and 0.07 for day.

Table 6. Sensory evaluation of bratwurst sausage and loin chops from carcasses of pigs fed 4 levels of distillers dried grains with solubles (DDGS)[1]

	DDGS, %					P-value	
Item	0	15	30	45	SE	Linear	Quadratic
Sensory evaluation of bratwurst sausage[2]							
Texture[3]	8.46	6.97	7.38	6.52	0.27	0.004	0.29
Juiciness[4]	6.70	7.50	7.38	8.19	0.37	0.04	0.99
Off flavor[5]	2.61	2.76	2.56	2.82	0.25	0.72	0.84
Sensory evaluation of loin chops[2]							
Tenderness[6]	8.34	7.89	8.13	8.63	0.37	0.52	0.24
Juiciness[4]	5.09	5.20	5.06	5.68	0.64	0.60	0.71
Off flavor[5]	6.62	5.55	5.50	5.46	0.49	0.17	0.34

[1]Means based on 3 replications of 5 pigs per pen (n = 15 per treatment).

[2]Sensory evaluation was performed by a trained, 8-member panel.

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

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

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

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

cooked bacon slices. Also, no off flavors were associated with increased DDGS in the diet. Other recent studies that included varying levels of DDGS in the diet also reported no effect on tenderness or off flavors in cooked bacon slices among treatments (Widmer et al., 2008; Xu et al., 2010b).

Bratwurst-style Sausage

The effects of DDGS in the diet on the objective color evaluation during the simulated retail display are shown in Table 5. Differences ($P < 0.001$) in color patterns existed among daily sampling periods, averaged across dietary treatments. Among treatments, there were quadratic effects in a^* color scores ($P < 0.02$) and hue angle scores ($P < 0.04$). Although the pattern was not consistent with level of DDGS fed, there was some evidence that sausage from pigs fed the greatest amount of DDGS tended to lose some of its red color compared with the other treatment groups. The L^*, b^*, and chroma scores did not differ among treatments. There were no treatment × day interactions among any of the color measurements.

The TBARS values, also shown in Table 5, tended to increase (except for d 5) during the simulated retail display for all treatments, resulting in a cubic response ($P < 0.02$), indicating lipid oxidation was occurring. Averaged across observation periods, there was no effect of dietary treatment; however, there was a treatment × diet interaction that approached significance ($P < 0.06$). A separate analysis of the data on d 7 indicated that TBARS increased linearly ($P < 0.03$) in sausage from pigs fed the greater levels of DDGS on d 7 of observation. Expressed another way, TBARS increased more from d 0 to 7 in sausage from pigs fed the 2 greater levels of DDGS (increases of 0.24 and 0.46 mg/kg, respectively) than those fed the 2 lesser levels of DDGS (increase of 0.04 and decrease of 0.03 mg/kg, respectively). A statistical analysis of these changes from d 0 to 7 indicated that the increase in TBARS was linearly ($P < 0.005$) affected by DDGS in the consumed diet.

Unsaturated fatty acids are generally more susceptible to lipid oxidation due to the weaker, double-bond structure (McClements, 2004). Changes in the fatty acid profile may lead to adverse effects in shelf life, including color stability and lipid oxidation (Wood et al., 2003). Correa et al. (2008) suggested that softer pork fat or more unsaturated fat tends to have shorter shelf life. Although the effects of DDGS on objective color and TBARS scores were relatively minor in this study, the changes in fatty acid profiles are assumed to be responsible for these effects.

Sensory evaluations of the effects of DDGS in the diet on bratwurst-style sausage are shown in Table 6. The addition of DDGS to the diet increased the juiciness (linear, $P < 0.04$) scores. In addition, the sausage was scored as having a softer texture (linear, $P < 0.004$), which was probably due to the increased softness of the fat. No differences in off flavor were observed among the treatments ($P > 0.05$). In a study with sows, feeding 30% DDGS during gestation and 15% DDGS during lactation resulted in a "less desirable" appearance ($P < 0.05$) of fresh or cooked bratwurst sausage, but it did not affect texture, taste, or overall acceptability by a taste panel (Wert et al., 2009). Other than the study with sow sausage, very little, if any, other research on the organoleptic evaluation of sausage from the feeding of increased amounts of DDGS has been reported in peer-reviewed publications.

Loins

Swine diets formulated with DDGS did not alter tenderness, juiciness, or off-flavor characteristics of loin chops (Table 6). These results are in agreement with Widmer et al. (2008) and Xu et al. (2010b), who found that DDGS did not affect organoleptic traits of pork loin chops.

Conclusions

In summary, results indicate that adding increased amounts of DDGS (30% or 45%) to the diet results in softer bellies, greater PUFA concentrations in carcass fat, and greater iodine values, but it does not negatively affect slicing integrity, shatter scores, and eating quality of bacon slices or sensory attributes of Bratwurst-style sausage and loin chops. Increased DDGS in the diet resulted in an abbreviated color and increased lipid oxidation, which could be attributed to the increase in PUFA. Because the softer bellies with greater PUFA concentrations and greater iodine values did not produce bellies and bacon slices of inferior quality, the overall consumer acceptance would not be expected to be negatively altered with the addition of increased amounts of DDGS in swine diets.

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