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Effects of feeding pelleted diets without or with distillers dried grains with solubles on fresh belly characteristics, fat quality, and commercial bacon slicing yields of finishing pigs[1]

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ABSTRACT: One hundred ninety-two pigs were blocked by age and stratified by initial BW (25.7 ± 2.3 kg) into pens (2 barrows and 2 gilts/pen), and within blocks, pens were assigned randomly to 1 of 4 treatments in a 2 × 2 factorial arrangement, with main effects of diet form (meal vs. pelleted) and distillers dried grains with solubles (DDGS) inclusion (0% vs. 30%). Pigs were slaughtered after a 91-d feeding trial, and carcasses were fabricated after a 24-h chilling period. Belly dimensions and flop distance were measured, and an adipose tissue sample from each belly was collected for fatty acid analysis. Bacon was manufactured at a commercial processing facility before being returned to the University of Illinois Meat Science Laboratory for further evaluation. Although bellies from pigs fed pelleted diets were 5.3% heavier ($P < 0.01$) than bellies from meal-fed pigs, belly weight as a percentage of chilled side weight ($P = 0.55$) and fresh belly dimensions ($P \geq 0.11$) were not affected by diet form. Slab bacon weight and cooked yield were greater ($P \leq 0.01$) for bellies from pellet-fed than meal-fed pigs. Despite pellet-fed pigs having a 3.1-unit greater iodine value (IV) than meal-fed pigs, there was no effect ($P \geq 0.16$) of diet form on commercial bacon slicing yields. Bacon slabs from pellet-fed pigs produced more ($P < 0.01$) total bacon slices, but 3.1% fewer ($P < 0.01$) slices per kilogram than slabs from meal fed pigs. Inclusion of 30% DDGS reduced belly thickness ($P < 0.001$), flop distance ($P < 0.001$), and initial belly weight ($P = 0.04$) by 0.32 cm, 4.97 cm, and 2.85, respectively, and increased ($P < 0.001$) belly fat IV by 7.1 units compared with bellies from pigs fed 0% DDGS. Feeding 0% DDGS produced more ($P < 0.01$) total bacon slices than feeding 30% DDGS. Distillers dried grains with solubles inclusion had no effect on slice yields ($P \geq 0.14$) or slices per kilogram ($P = 0.08$). Overall, bellies from pellet-fed pigs were heavier and had greater IV but did not differ in commercial slicing yields from meal-fed pigs. Feeding pigs 30% DDGS produced thinner, softer bellies with greater IV, but slicing yields were not different from bellies of pigs fed 0% DDGS. Thus, swine producers can feed pelleted diets, without or with 30% DDGS, without negatively affecting commercial bacon slicing yield.

Key words: commercial bacon slicing, diet form, distillers dried grains with solubles, iodine value, pelleting, pork belly

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INTRODUCTION

Pelleted diets are fed to pigs to improve growth performance (Hancock and Behnke, 2001), in particular the rate of gain and feed efficiency by 5% to 8% (Wondra et al., 1995; Myers et al., 2013). The improvement in growth performance is due to increased

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nutrient digestibility, particularly of fat (Noblet and van Milgen, 2004) and starch (Bengala Freire et al., 1991; Rojas et al., 2016). However, pelleting increased the iodine value (**IV**) of belly fat by 2 to 3 units compared with feeding a meal diet (Matthews et al., 2014; Nemechek et al., 2015). The IV is an indicator of fat quality and is often used to predict the functionality of fat in further processed products, especially bacon slicing yields. Reductions in bacon slicing yield have been reported in bellies that have greater proportions of PUFA (Shackelford et al., 1990) and greater IV than their counterparts (Kyle et al., 2014), yet calculated IV is poorly related to commercial bacon slicing yields ($r = -0.15$; Kyle et al., 2014). Furthermore, the inclusion of distillers dried grains with solubles (**DDGS**) increased the IV of belly fat but did not affect commercial bacon slicing yields of barrows (Tavárez et al., 2014). Even so, little is known about the effects of feeding a pelleted diet, without or with DDGS, to growing-finishing pigs on commercial bacon slicing yields. Therefore, the objective of this experiment was to determine the effects of feeding pelleted diets formulated with 0% or 30% DDGS on fresh belly characteristics, fat quality, and commercial bacon slicing yields of growing-finishing pigs.

MATERIALS AND METHODS

Experimental procedures for the live-phase portion of the study were reviewed and approved by the University of Illinois Institutional Animal Care and Use Committee.

Experimental Design and Dietary Treatments

Pigs (192 total; Génétiporc G-Performer boars × Fertilis-25 sows; Alexandria, MN) were blocked by age and stratified by initial BW (25.7 ± 2.3 kg; Overholt et al., 2016). Within each block, 6 pens (2 barrows and 2 gilts/pen) were randomly assigned to 1 of 4 treatments in a 2 × 2 factorial arrangement with 2 diet forms (meal vs. pelleted) and 2 DDGS inclusion levels (0 vs. 30%). Pen was the experimental unit for all dependent variables. Descriptions of diet formulation and composition, feeding program, and housing environment are detailed by Overholt et al. (2016). At the conclusion of the 91-d feeding trial, pigs with an average BW of 112.9 ± 4.9 kg were transported to the University of Illinois Meat Science Laboratory and slaughtered under USDA Food Safety and Inspection Service (**FSIS**) supervision.

Carcass Fabrication and Fresh Belly Characteristics

Carcasses were allowed to chill at 4°C for approximately 24 h after slaughter. The left sides of each carcass were weighed to determine chilled side weight. Then, left sides were fabricated into primals, and the fresh, skin-on bellies ($N = 186$) were collected and fabricated in accordance with the North American Meat Processors Association (**NAMP**) into NAMP #408 pork bellies (NAMP, 2010). Bellies from the first slaughter day were allowed to equilibrate at 4°C for 72 h, and bellies from the second slaughter day were allowed to equilibrate for 24 h at 4°C, such that all bellies within each block were evaluated on the same day. All bellies were laid flat on a table and covered with butcher paper and cellophane wrap to minimize evaporative loss. Following equilibration, fresh bellies were evaluated for width at the midpoint of the longitudinal axis and length at the midpoint of the latitudinal axis. Belly thickness was determined by forcing a sharpened back fat probe through the medial side of the belly at the midpoint between the latitudinal axis on the dorsal ($n = 4$ measurements) and ventral edges ($n = 4$ measurements) at 0%, 40%, 60%, and 80% of the length of the belly beginning at the anterior end. The 8 measurements were averaged for all statistical analyses. Flop distance was determined by measuring the distance between the skin of a belly draped skin side down over a stationary bar. An adipose tissue sample, containing all 3 fat layers and free of lean tissue, was collected for fatty acid profile analysis on each belly from the dorsal edge of the anterior end of the belly. Bellies were then identified, vacuum packaged, and frozen at −29°C until processing into bacon.

Fatty Acid Profile and Concentrations of Belly Adipose Tissue

Adipose tissue samples for fatty acid methyl esters (**FAME**) analysis were prepared using the procedure of Tavárez et al. (2012), with some modifications. Adipose tissue samples, free of lean tissue and skin, were submerged in liquid N_2 until completely frozen and then pulverized and homogenized in a blender (Waring Products, Torrington, CT). Approximately 100 to 140 mg of the resulting powder was prepared for FAME extraction according to the procedure described by the American Oil Chemists' Society (**AOCS**, 1998; method Ce 2-66). Samples were first extracted in 5 mL isooctane; then a 0.5-mL aliquot was transferred to gas chromatography vials and diluted 1:1 with isooctane (total dilution factor of 10). The resulting FAME extracts were analyzed using a gas chromatograph (Hewlett-Packard 5890 Series II;

Agilent Technologies, Santa Clara, CA) equipped with an autosampler and a DB-Wax capillary column (30 m × 0.25 m × 0.25 μm film coating; Agilent Technologies, Santa Clara, CA). The equipment was operated under a constant pressure of 1.30 kg/cm^2 using He gas as the carrier and a 100:1 split ratio. The temperature of the injector was held at 250°C, and the temperature of the flame-ionization detector was held at 260°C. The oven temperature was held at 170°C for 2 min and increased 4°C/min to 240°C and then held constant for 12.5 min. The resulting chromatograph peaks were integrated using Agilent Chemstation software for gas chromatograph systems (version B.01.02; Agilent Technologies). Peaks were identified using a gas chromatograph reference standard (GLC 461 A, Nucheck-prep, Elysian, MN). Fatty acid methyl esters were normalized such that the area under each peak was calculated as a percentage of the total area. Fatty acid profile data were calculated as grams of FAME per 100 g total FAME. Iodine value was calculated using the AOCS (1998) equation: IV = [(C16:1) × 0.95] + [(C18:1) × 0.86] + [(C18:2) × 1.732] + [(C18:3) × 2.616] + [(C20:1 × 0.785] + [(C22:1) × 0.723], where values in parentheses indicate concentrations of the specific FAME as a percentage of total FAME. Total SFA, PUFA, and MUFA were also calculated.

In addition to fatty acid profile, the contents of particular fatty acids in belly adipose tissue were determined. First, milligrams of FAME per 100 g of adipose tissue were calculated using the following equation: [mg FAME/(adipose tissue weight, g/dilution factor, 10)] × 100. The calculated concentrations of FAME were then converted to milligrams of fatty acid per 100 g adipose tissue (method Ce 1j-07; AOCS, 2009).

Bacon Manufacturing

Frozen, vacuumed-packaged bellies were allowed to thaw for approximately 36 h at 4°C. Thawed bellies were then sorted by treatment and skinned, yielding an NAMP #409 skinless belly. Bellies were then weighed to collect initial weight. Bellies were repackaged with an identification tag and transported in a refrigerated truck to a USDA-FSIS-inspected bacon manufacturing facility for further processing. Bellies were injected by treatment group with a typical commercial cure solution formulated to deliver 1.35% salt at a pump uptake of 13%. Bellies were weighed immediately after injection to measure pumped weight to calculate the percentage of pump uptake. Pump uptake was calculated with the following equation: pump uptake = [(pumped weight − initial weight)/initial weight] × 100. Injected bellies were then hung on smokehouse racks and thermally processed using a step-up cooking cycle for approximately 4 h to an internal belly temperature of 53.3°C. Treatments were arranged within the smokehouse such that each treatment was equally represented in the front, center, and back as well as to the left and right of the smokehouse to minimize the effect of cold or hot spots during cooking. Thermally processed bellies were chilled for approximately 36 h to an internal temperature between −5.6°C and −4.4°C. Weights of individual cured and smoked bellies were recorded to calculate cooked-chilled weight using the following equation: cooked-chilled yield = [(cooked-chilled weight − initial weight)/initial weight] × 100. Bellies were then pressed (22 to 24 cm wide and 35 to 38 mm deep) and sliced (27 to 31 slices/kg) beginning with the anterior (blade) end according to the bacon processing plant's standard protocols. Completely sliced bellies were sorted by trained facility personnel familiar with the manufacturer's grading procedures, placed on a U-board, and boxed to maintain anatomical orientation (anterior to posterior). Sliced and boxed bellies were then transported to the University of Illinois Meat Science Laboratory for further analysis.

Sliced Bacon Characteristics

The weight of bacon slices was recorded to calculate commercial bacon slicing yield as a percentage of initial belly weight ([sliced weight/initial weight] × 100) and as a percentage of cooked-chilled weight ([sliced weight/initial weight] × 100; Kyle et al., 2014; Tavárez et al., 2014). Slabs of sliced bacon were oriented from the anterior end to the posterior end to count the total number of slices from each belly and were used to calculate slices per kilogram (number of slices/sliced belly weight). Bellies were then divided into 5 equal zones (designated A, B, C, D, and E) starting at the anterior end, with an approximately equal number of slices in each zone (Robles, 2004; Kyle et al., 2014), and 2 slices from each zone were collected, homogenized in a food processor (CUI DFP-7BC; Cuisinart, East Winsdsor, NJ), and analyzed for moisture percentage (AOAC, 2007) and extractable lipid (Novakofski et al., 1989). A slice from the approximate center of zones A, C, and E was collected, identified by pig and location, placed on rigid nonstick cardboard (taking care not to distort or stretch the slice), vacuum packaged, boxed, and frozen until photographed for image analysis.

Bacon Slice Image Analysis

Bacon slice image analysis was conducted using the procedure described by Kyle et al. (2014). Frozen slices from zones A (blade end), C (center), and E

Table 1. Effects of diet form and distillers dried grains with solubles (DDGS) on fresh belly characteristics

	Diet Form			DDGS			*P*-value		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet form	DDGS	Diet form × DDGS
No. of pens	24	24		24	24				
Belly wt, kg	6.39	6.73	0.13	6.62	6.49	0.13	<0.01	0.13	0.99
Percent of chilled side wt[1]	15.09	15.21	0.18	15.31	14.98	0.18	0.55	0.11	0.68
Length, cm	64.55	64.96	0.36	64.93	64.58	0.36	0.26	0.33	0.46
Width, cm	28.06	28.45	0.26	28.19	28.42	0.26	0.11	0.17	0.72
Thickness,[2] cm	3.58	3.66	0.05	3.78	3.46	0.05	0.12	<0.0001	0.48
Flop distance, cm	11.64	10.85	0.77	13.73	8.76	0.77	0.44	<0.0001	0.76
Thaw loss, %	1.63	1.57	0.07	1.61	1.59	0.07	0.55	0.80	0.13

[1]Belly as a percentage of chilled side weight was calculated as (weight of left belly, kg/weight of 24-h chilled left carcass side) × 100.

[2]Thickness was average of measurements taken at 8 locations from the anterior to posterior, with 4 measurements on each of the dorsal and ventral edges, respectively.

(flank end) were removed from their vacuum packaging, placed on a blue background, and photographed using a Nikon D60 camera (Nikon Instruments Inc., Melville, NY). A ruler was included in each image to calibrate dimensions during image analysis. The background of each image was erased using the magic wand tool, and the image was converted to a TIFF file in Adobe Photoshop CS6 (Adobe Systems Inc., San Jose, CA). Image analysis was conducted using National Institutes of Health image processing and analysis in Java software ImageJ (Abramoff et al., 2004). Threshold values were adjusted as needed within each image to account for variation in lean and fat color. Total slice length, width, total slice area, primary lean area, and secondary lean (cutaneous trunci) area (Person et al., 2005) were calculated by pixel density in ImageJ for each slice. Total slice, primary lean, and secondary lean areas were used to calculate total lean area (primary lean area + secondary lean area), percentage lean area ([total lean area/total slice area] × 100), total fat area (total slice area − total lean area), and lean-to-fat ratio (total lean area/total fat area).

Statistical Analyses

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) as a 2 × 2 factorial arrangement of treatments in a randomized complete block design, and pen ($N = 48$) was the experimental unit. Fixed effects were diet form (meal vs. pellet), DDGS inclusion (0% vs. 30%), and the interactive effect of diet form and DDGS inclusion (12 replications of each treatment combination). Block and replication nested within block served as random effects. Assumptions of ANOVA were tested with Levene's test and the Brown-Forsythe test for homogeneity of variances, and the normality of the residuals was tested using the UNIVARIATE procedure of SAS. Least squares means of main effects and interactive effects were separated using the PDIFF option of the MIXED procedure and were considered significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

Fresh Belly Characteristics

There were no interactions ($P \geq 0.13$) between diet form and DDGS inclusion for any fresh belly characteristics (Table 1). Pellet-fed pigs produced 5.3% heavier ($P < 0.01$) skin-on bellies than meal-fed pigs; however, skin-on belly weight as a percentage of chilled side weight was not affected ($P = 0.55$) by diet form. Diet form did not affect ($P \geq 0.11$) belly length, width, thickness, flop distance, or thaw loss. There was no effect ($P \geq 0.11$) of DDGS inclusion on skin-on belly weight, skin-on belly weight as a percentage of chilled side weight, length, width, or thaw loss. Inclusion of 30% DDGS reduced ($P < 0.0001$) belly thickness by 0.32 cm and decreased ($P < 0.0001$) flop distance by 4.97 cm, similar to the results of Leick et al. (2010). However, Xu et al. (2010) reported that feeding 30% DDGS increased belly fat PUFA content and reduced belly firmness score but had no effect on belly thickness. Even though belly firmness and thickness are well correlated ($r = 0.59$; Kyle et al., 2014), belly firmness is more strongly correlated with PUFA concentration ($r = -0.64$; Kyle et al., 2014).

Fatty Acid Profile and Fatty Acid Concentrations of Belly Adipose Tissue

Bellies from pellet-fed pigs had greater ($P \leq 0.03$) proportions of linoleic acid (C18:2*n*6), α-linolenic acid (C18:3*n*3), and eicosatrienoic acid (C20:3*n*3) and lower ($P \leq 0.05$) proportions of capric acid (C10:0), myristic acid (C14:0), myristoleic acid (C14:1), pentadecenoic

Table 2. Effects of diet form and distillers dried grains with solubles (DDGS) on the fatty acid methyl ester profile of belly adipose tissue (g FAME/100 g total FAME)

	Diet form			DDGS			*P*-value		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet form	DDGS	Diet form × DDGS
No. of pens	24	24		24	24				
C10:0	0.08	0.08	0.001	0.09	0.08	0.001	0.05	<0.0001	0.37
C12:0	0.08	0.08	0.001	0.08	0.08	0.001	0.25	0.07	0.04
C14:0	1.40	1.34	0.01	1.41	1.33	0.01	<0.01	<0.01	0.95
C14:1	0.01	0.00	0.002	0.01	0.01	0.002	0.05	0.34	0.39
C15:0	0.06	0.05	0.002	0.05	0.06	0.002	<0.0001	<0.01	0.16
C16:0	22.66	21.99	0.13	23.07	21.58	0.13	<0.01	<0.0001	0.76
C16:1	2.66	2.30	0.03	2.73	2.24	0.03	<0.0001	<0.0001	0.09
C17:0	0.37	0.29	0.007	0.32	0.34	0.007	<0.0001	0.06	0.28
C17:1	0.39	0.30	0.01	0.36	0.33	0.01	<0.0001	<0.01	0.38
C18:0	9.66	9.67	0.09	10.09	9.24	0.09	0.94	<0.0001	0.64
C18:1	43.55	41.92	0.16	44.41	41.05	0.16	<0.0001	<0.0001	0.99
C18:2*n*6	16.13	18.86	0.24	14.55	20.44	0.24	<0.0001	<0.0001	0.86
C18:3*n*6	0.03	0.02	0.003	0.02	0.03	0.003	0.09	<0.01	0.98
C18:3*n*3	0.55	0.59	0.01	0.53	0.61	0.01	<0.01	<0.0001	0.13
C20:0	0.19	0.19	0.002	0.19	0.18	0.002	0.94	<0.01	0.70
C20:1*n*9	0.77	0.76	0.01	0.77	0.75	0.01	0.75	0.09	0.07
C20:2*n*6	0.69	0.82	0.01	0.65	0.87	0.01	<0.0001	<0.0001	0.29
C20:3*n*6	0.12	0.12	0.002	0.11	0.13	0.002	0.09	<0.0001	0.67
C20:4*n*6	0.30	0.30	0.005	0.28	0.32	0.005	0.89	<0.0001	0.48
C20:3*n*3	0.09	0.10	0.001	0.09	0.10	0.001	0.03	<0.01	0.33
C22:0	0.000	0.001	0.001	0.000	0.001	0.001	0.22	0.21	0.71
C22:1*n*9	0.000	0.002	0.001	0.000	0.002	0.001	0.23	0.24	0.81
C22:4*n*6	0.13	0.13	0.002	0.12	0.15	0.002	0.60	<0.0001	0.63
C22:5*n*6	0.06	0.06	0.003	0.06	0.06	0.003	0.10	0.99	0.58
C22:6*n*3	0.01	0.01	0.003	0.01	0.01	0.003	0.80	0.73	0.83
Total SFA[1]	34.50	33.69	0.2	35.29	32.89	0.2	<0.01	<0.0001	0.64
Total PUFA[2]	18.13	21.02	0.26	16.43	22.72	0.26	<0.0001	<0.0001	0.86
Total MUFA[3]	47.38	45.29	0.18	48.28	44.38	0.18	<0.0001	<0.0001	0.75
IV[4]	70.03	73.11	0.35	68.02	75.11	0.35	<0.0001	<0.0001	0.67

[1]Total SFA = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

[2]Total PUFA = C18:2*n*6 + C18:3*n*6 + C18:3*n*2 + C20:2*n*6 + C20:3*n*6 +C20:4*n*6 + C20:3*n*3 + C22:4*n*6 + C22:5*n*6 +C22:6*n*3.

[3]Total MUFA = C14:1 + C16:1 + C17:1 + C18:1 + C20:1*n*9 + C22:1*n*9.

[4]Iodine value = [(C16:1) × 0.95] + [(C18:1) × 0.86] + [(C18:2) × 1.732] + [(C18:3) × 2.616] + [(C20:1 × 0.785] + [(C22:1) × 0.723], where values in parentheses indicate concentrations of the specific FAME as a percentage of total FAME.

acid (C15:0), palmitic acid (C16:0), palmitoleic acid (C16:1), margaric acid (C17:0), heptadecenoic acid (C17:1), and oleic acid (C18:1) than bellies from meal-fed pigs (Table 2). Bellies from pellet-fed pigs had a 2.89 g/100 g greater ($P < 0.0001$) total PUFA and 2.09 and 0.89 g/100 g less ($P \leq 0.01$) total MUFA and SFA, respectively. The greater proportion of PUFA in bellies from pellet-fed pigs resulted in a 3.08-unit increase ($P < 0.0001$) in IV compared with bellies of meal-fed pigs.

Fatty acid concentrations of belly adipose tissue (mg fatty acid/100 g adipose tissue) was largely reflective of the fatty acid profile, with some exceptions (Table 3). Although belly adipose tissue of pellet-fed pigs had lower proportions of C14:0, C16:0, and C18:1 FAME than meal-fed pigs, diet form did not affect ($P \geq 0.42$) the concentrations of these fatty acids in the adipose tissue. Moreover, pellet-fed pigs had greater ($P \leq 0.01$) concentrations of C18:2*n*6, C18:3*n*3, and C20:2*n*6 and lower ($P \leq 0.01$) concentrations of C16:1, C17:0, and C17:1.

Considering both the FAME proportions and fatty acid concentrations, it is clear that the increase in PUFA observed in pellet-fed pigs occurred primarily at the expense of MUFA, with diet form largely not affecting SFA. The shift in fatty acid profile was similar to that reported by Nemechek et al. (2015) and Matthews et al. (2014), who observed that pigs fed pelleted diets had a greater proportion of PUFA in belly

Table 3. Effects of diet form and distiller's dried grains with solubles on the contents of selected fatty acids of belly adipose tissue (mg FA/100 g adipose tissue)[1]

	Diet form			DDGS			*P*-value		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet form	DDGS	Diet form × DDGS
No. of pens	24	24		24	24				
C14:0	0.88	0.86	0.02	0.91	0.83	0.02	0.42	<0.01	0.43
C16:0	14.31	14.23	0.36	14.99	13.55	0.36	0.75	<0.0001	0.26
C16:1	1.69	1.49	0.05	1.77	1.41	0.05	<0.01	<0.0001	0.59
C17:0	0.23	0.19	0.01	0.21	0.21	0.01	<0.0001	0.55	0.29
C17:1	0.25	0.19	0.01	0.23	0.21	0.01	<0.0001	<0.01	0.61
C18:0	6.12	6.29	0.16	6.59	5.82	0.16	0.21	<0.0001	0.22
C18:1	27.63	27.21	0.65	28.97	25.87	0.65	0.42	<0.0001	0.32
C18:2*n*6	10.15	12.10	0.21	9.45	12.80	0.21	<0.0001	<0.0001	0.58
C18:3*n*3	0.35	0.38	0.01	0.34	0.38	0.01	<0.01	<0.0001	0.72
C20:0	0.12	0.12	0.004	0.13	0.12	0.004	0.39	<0.01	0.59
C20:1*n*9	0.49	0.50	0.01	0.51	0.48	0.01	0.35	<0.01	0.03
C20:2*n*6	0.44	0.53	0.01	0.42	0.55	0.01	<0.0001	<0.0001	0.19
C20:4*n*6	0.19	0.19	0.004	0.18	0.20	0.004	0.50	<0.01	0.93

[1]Fatty acids displayed are those that were detected at concentrations greater than 0.10 mg/100 g of adipose tissue.

adipose tissue, leading to a greater IV. Pelleting diets increases fat digestibility (Noblet and van Milgen, 2004; Xing et al., 2004), DM, nitrogen, GE (Wondra et al., 1995), and starch (Bengala Freire et al., 1991; Rojas et al., 2016). In pigs fed diets in which almost all energy is provided as starch, de novo fatty acid synthesis accounts for 86% of all nonessential fatty acids deposited in adipose tissue, typically as SFA and MUFA (Kloareg et al., 2007); however, when fat is added to the diet, de novo synthesis is reduced, and exogenous fatty acids from the diet are deposited in adipose tissue at a greater concentration (Azain, 2004). By increasing digestibility of fat, de novo fatty acid synthesis is likely reduced, similar to what occurs when dietary fat is increased. Corn contains a relatively high concentration of C18:2*n*6 (NRC, 2012), and with increased digestibility of fat suppressing de novo fatty acid synthesis, a greater proportion of the C18:2*n*6 from the diet will be deposited in adipose tissue. Furthermore, the increased digestibility of starch will reduce the amount of fat needed to meet energy requirements, thereby increasing the proportion of dietary fatty acids available for deposition.

Feeding 30% DDGS increased ($P \leq 0.01$) proportions of pentadecenoic (C15:0), linoleic (C18:2*n*6), γ-linolenic (C18:3*n*6), α-linolenic (C18:3*n*3), eicosadienoic (C20:2*n*6), dihomo-γ-linolenic (C20:3*n*6), arachidonic (C20:4*n*6), eicosatrienoic (C20:3*n*3), and adrenic (C22:4*n*6) acids but decreased ($P \leq 0.01$) proportions of capric (C10:0), myristic (C14:0), palmitic (C16:0), palmitoleic (C16:1), heptadecenoic (C17:1), stearic (C18:0), oleic (C18:1), and arachidic (C20:0) acids compared with feeding 0% DDGS (Table 2). Thus, belly adipose tissue from pigs fed 30% DDGS had 6.29 g/100 g more ($P < 0.0001$) PUFA and 2.40 and 7.09 g/100 g less ($P < 0.0001$) SFA and MUFA, respectively, resulting in a 7.09-unit increase ($P < 0.0001$) in belly adipose IV compared with bellies from pigs fed 0% DDGS.

Fatty acid concentrations of belly adipose tissue (mg fatty acid/100 g adipose tissue) were largely reflective of the proportional profile (Table 3). Feeding 30% DDGS increased ($P \geq 0.01$) concentrations of all PUFA and decreased concentrations of all MUFA ($P \geq 0.01$). Feeding 30% DDGS also decreased ($P \geq 0.01$) concentrations of C14:0, C16:0, C18:0, and C20:0, but DDGS inclusion level did not affect ($P = 0.55$) concentrations of C17:0. The increase in PUFA concentration and IV, with a concurrent decrease in both MUFA and SFA, in pigs fed DDGS is in agreement with previous research (Leick et al., 2010; Xu et al., 2010; Tavárez et al., 2012).

Commercial Bacon Processing and Slicing

Bellies from pigs fed 30% DDGS took up more ($P \leq 0.02$) brine than those from pigs fed 0% DDGS, and between bellies of DDGS-fed pigs, pump uptake was greater ($P = 0.01$) when diets were pelleted, whereas between bellies of pigs fed no DDGS, pump uptake was greater ($P < 0.01$) when diets were fed in meal form (diet form × DDGS inclusion, $P < 0.001$; Table 4). This relationship is likely due to differences in extractable lipid among the treatments, as the hydrophilic

Table 4. Effects of diet form and distillers dried grains with solubles (DDGS) on commercial bacon processing characteristics and slicing yields

	Diet Form			DDGS			*P*-value		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet form	DDGS	Diet form × DDGS
No. of pens	24	24		24	24				
Initial wt, kg	5.29	5.64	0.11	5.54	5.38	0.11	<0.0001	0.04	0.87
Pumped wt, kg	6.15	6.54	0.13	6.40	6.28	0.13	<0.01	0.19	0.54
Pump uptake, %	16.15	16.08	0.12	15.47	16.76	0.12	0.67	<0.0001	<0.01
Cooked and pressed wt, kg	5.54	5.95	0.12	5.80	5.70	0.12	<0.0001	0.25	0.76
Cooked yield, %	104.61	105.63	0.18	104.48	105.77	0.18	<0.01	<0.0001	0.40
Sliced wt, kg	4.93	5.31	0.10	5.17	5.06	0.10	<0.0001	0.14	0.54
Slicing yield (initial wt), %	93.14	94.28	0.56	93.38	94.04	0.56	0.16	0.41	0.26
Sliced yield (cooked wt), %	89.02	89.26	0.51	89.37	88.90	0.51	0.75	0.52	0.16
Number of slices	184	192	2.85	192	184	2.85	<0.01	<0.01	0.42
Slices per kg of sliced belly	37.4	36.2	0.33	37.2	36.4	0.33	<0.01	<0.08	0.06

lean tissue is able to retain more brine than hydrophobic adipose tissue (Lowe, 2013).

Initial weight, pumped weight, cooked weight, and sliced weight were heavier ($P \leq 0.01$) for bellies from pellet-fed pigs than from meal-fed pigs (Table 4). Cooked yield of bellies from pellet-fed pigs was greater ($P < 0.01$) than that of bellies of meal-fed pigs; however, despite differences in IV between belly adipose tissue from meal- and pellet-fed pigs and between pigs fed 0% and 30% DDGS, there were no differences ($P \geq 0.16$) in commercial bacon slicing yields as a percentage of initial weight ($P = 0.16$) or cooked weight ($P = 0.75$). Belly adipose IV may be poorly correlated ($r = -0.15$; Kyle et al., 2014) with commercial bacon slicing yield, but Kyle et al. (2014) reported a 3.03-unit difference in IV between barrows and boars that corresponded to a 3.8% difference in commercial bacon slicing yield. Conversely, Tavárez et al. (2014) reported no difference in commercial bacon slicing yield in barrows fed 0% or 30% DDGS, despite there being an 8.58-unit difference in IV. This implies that there are other factors that contribute to the relationship between IV and commercial bacon slicing yield. For example, belly thickness and moisture content were more strongly correlated with commercial bacon slicing yield than IV (Kyle et al., 2014).

Bacon slabs from pigs fed pelleted diets yielded 4.5% more ($P < 0.01$) slices than those from pigs fed meal diets, and bacon slabs from pigs fed 0% DDGS yielded 4.2% more ($P < 0.01$) slices than slabs from pigs fed 30% DDGS (Table 4). The number of slices per kilogram of sliced belly was 3.2% greater ($P < 0.01$) in bacon manufactured from meal-fed pigs than from pellet-fed pigs, but there was no effect ($P = 0.08$) of DDGS inclusion on slices per kilogram of sliced belly. This effect on slice consistency is likely of little consequence to processors marketing bacon on only a weight basis. However, for processors marketing bacon on a per slice basis, a greater number of slices per kilogram presents an opportunity to increase revenue from each belly.

Slice Image Analysis and Bacon Composition

Visual lean-to-fat ratio (**lean:fat**) as well as slice dimensions are important traits that influence consumers' purchasing decisions and acceptability of bacon. Bacon from "thick" bellies, which have a lower lean:fat than "thin" bellies, are less preferred and therefore are less likely to be purchased by consumers (Person et al., 2005). Although there was no effect of diet form on fresh belly thickness or width, slices from bellies of pigs fed pelleted diets with 0% DDGS were shorter ($P \leq 0.03$) than bacon slices from the other 3 treatment combinations (diet form × DDGS inclusion, $P < 0.01$; Table 5). Furthermore, bacon slices from pigs fed 0% DDGS in pellet form were wider ($P < 0.01$) than slices from pigs fed 30% DDGS in pellet form, and slices from pellet-fed pigs and pigs fed 30% DDGS in meal form were wider ($P \leq 0.04$) than slices from pigs fed meal diets with 0% DDGS (diet form × DDGS inclusion, $P < 0.01$). Both Leick et al. (2010) and Little et al. (2014) reported that pigs fed 30% DDGS had longer slices than slices from pigs fed no DDGS and hypothesized that the difference in slice length could be due to the greater concentration of unsaturated fats, contributing to a more elastic structure than slices with a firmer, more saturated fat. Slice width typically corresponds to belly thickness, which was not the case in the present experiment. There was no difference ($P = 0.39$) in slice width between pigs fed 30% DDGS regardless of diet form, but slices from pigs fed 30% DDGS were wider ($P \leq 0.04$) than slices from pigs

Table 5. Effects of feeding pelleted diets without or with 30% distillers dried grains with solubles (DDGS) on slice image analysis and proximate composition of bacon slices

	Meal		Pellet			*P*-value		
Item	0% DDGS	30% DDGS	0% DDGS	30% DDGS	SEM	Diet form	DDGS	Diet form × DDGS
No. of pens	12	12	12	12				
Total area, cm^2	91.48^{b}	94.50^{a}	95.79^{a}	96.02^{a}	0.90	<0.01	0.05	0.09
Primary lean area, cm^2	38.75	39.78	39.01	38.99	0.73	0.63	0.37	0.34
Secondary lean area, cm^2	10.44^{bc}	10.84^{ab}	9.83^{c}	11.35^{a}	0.24	0.84	<0.01	0.03
Total lean area, cm^2	49.20	50.62	48.84	50.34	0.89	0.66	0.05	0.96
Total fat area, cm^2	42.28^{c}	43.88^{bc}	46.94^{a}	45.68^{ab}	0.75	<0.0001	0.81	0.04
Slice length, cm	25.10^{a}	25.08^{a}	24.50^{b}	25.53^{a}	0.21	0.67	<0.01	<0.01
Slice width, cm	3.43^{c}	3.61^{ab}	3.72^{a}	3.56^{b}	0.04	<0.01	0.86	<0.01
Lean:fat	1.17	1.16	1.04	1.11	0.03	<0.01	0.41	0.17
Moisture, %	53.15^{a}	52.87^{a}	51.14^{b}	53.28^{a}	0.50	0.10	0.06	0.01
Extractable lipid, %	30.31^{b}	30.85^{b}	33.28^{a}	30.36^{b}	0.70	0.06	0.07	0.01

$^{a–c}$Within a row, least squares means lacking a common superscript differ ($P \leq 0.05$).

fed 0% DDGS in meal form. Total slice area of pigs fed pelleted diets was 2.91 cm^2 greater ($P < 0.01$) than slice area of pigs fed meal diets. The inclusion of DDGS had a similar effect, as pigs fed 30% DDGS had slices that were 1.63 cm^2 greater in area ($P = 0.05$) than slices from pigs fed 0% DDGS.

Total lean area of bacon slices from pigs fed 30% DDGS was 1.46 cm^2 greater ($P = 0.05$) than that from pigs fed 0% DDGS, but diet form did not affect ($P = 0.66$) total lean area (Table 5). In addition, neither diet form ($P = 0.63$) nor DDGS inclusion ($P = 0.37$) affected primary lean area. Even though secondary lean area did not differ ($P = 0.14$) between pigs fed 30% DDGS, regardless of diet form, slices from pigs fed pelleted diets with 30% DDGS had greater ($P \leq 0.01$) secondary lean area than slices from pigs fed no DDGS, regardless of diet form (diet form × DDGS inclusion, $P = 0.03$). Observed differences in secondary lean area were not likely a response to hypertrophy of the cutaneous trunci but were more related to the numerical difference in slicing yield among treatments. The size and dimensions of the cutaneous trunci change dramatically from the anterior to the posterior ends of the belly, being the largest in the center and tapering toward either end (Kauffman and St. Clair, 1965). During slicing and sorting, the best slices are generally in the center of the belly, whereas slices from both ends are less likely to meet the requirements for a #1 slice. This sorting process leaves the center slices with a greater proportion of secondary lean.

Total fat area was not different between 0% and 30% DDGS inclusion levels within both meal-fed ($P = 0.10$) and pellet-fed pigs ($P = 0.20$); however, bacon slices from pigs fed 0% DDGS in pellet form had 11.0% greater ($P < 0.0001$) total fat area than slices from pigs fed meal diets, regardless of DDGS inclusion level (diet form × DDGS inclusion, $P = 0.04$). Consequently, feeding pelleted diets reduced ($P < 0.01$) lean:fat compared with feeding meal diets, but lean:fat was not affected ($P = 0.41$) by DDGS inclusion. Previous research by Tavárez et al. (2014) reported no difference in lean:fat between pigs fed 0% and 30% DDGS and may be more reflective of differences in estimated carcass lean (Overholt et al., 2016). Not surprisingly, bacon from pigs fed a 0% DDGS diet in pellet form had the greatest ($P \leq 0.01$) percentage of extractable lipid and the least ($P \leq 0.01$) moisture content compared with the other 3 treatment combinations, which did not differ ($P \geq 0.54$) in percentage of extractable lipid or moisture (diet form × DDGS inclusion, $P \leq 0.01$).

CONCLUSIONS

The results of the present study confirm that both pelleting and including 30% DDGS in growing-finishing diets increased belly adipose tissue IV. More importantly, their respective effects on belly quality are largely additive, and pelleting does not disproportionately exacerbate belly quality issues associated with the inclusion of 30% DDGS in growing-finishing pig diets. Even though diet form and DDGS inclusion level had varying effects on belly quality traits, ultimately, neither treatment negatively affected commercial bacon slicing yields. Therefore, pork producers can feed pelleted diets, without or with 30% DDGS, to growing-finishing pigs without negatively affecting commercial bacon slicing yields.

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