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Effects of pelleting diets without or with distillers' dried grains with solubles on growth performance, carcass characteristics, and gastrointestinal weights of growing–finishing barrows and gilts[1]

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ABSTRACT: Pigs (192 total) were blocked by age and stratified by initial BW (25.75 ± 2.29 kg) into pens (2 barrows and 2 gilts per pen). Within blocks, pens were randomly allotted to treatments in a 2 × 2 factorial arrangement, with 2 diet forms (meal vs. pellet) and 2 distillers' dried grains with solubles (DDGS) inclusion levels (0 vs. 30%). Pigs were weighed at the beginning of the experiment and at the end of each feeding phase (d 35, 70, and 91) and daily feed allotments were recorded. Pigs were slaughtered at the end of the 91-d experiment, and full gastrointestinal (GI) tract and GI tract component weights were recorded immediately following evisceration. Carcass characteristics and meat quality were determined after a 24-h chill. Overall ADG was increased ($P < 0.01$) 3.2% when pigs were fed pelleted diets rather than meal diets, but there was no effect ($P = 0.46$) of DDGS inclusion on overall ADG. Overall ADFI of meal-fed pigs fed 30% DDGS was 4.7% greater ($P < 0.01$) than that of pigs fed 0% DDGS in meal form, but overall ADFI did not differ ($P \geq 0.19$) between DDGS inclusion level in pellet-fed pigs (diet form × DDGS inclusion, $P < 0.01$). When fed meal diets, pigs fed 0% DDGS had 2.7% greater ($P = 0.02$) overall G:F than pigs fed 30% DDGS; however, there was no difference ($P = 0.42$) in overall G:F between DDGS inclusion levels in pigs fed pelleted diets (diet form × DDGS inclusion, $P < 0.03$). Pigs fed pelleted diets had 2.9% heavier HCW ($P = 0.01$), 10.4% greater 10th-rib back fat ($P = 0.01$), and 1.8 percentage units less estimated lean percentage ($P = 0.04$) than meal-fed pigs. Full GI tracts of pigs fed pelleted diets were 0.33 percentage units less ($P = 0.03$) of the ending live weight than that of meal-fed pigs due to decreased ($P < 0.01$) GI tract contents. Inclusion of DDGS increased ($P = 0.03$) full GI tract weight, large intestine weight ($P < 0.01$), and GI tract contents ($P = 0.02$). Severity of parakeratosis of the pars esophagea was greater ($P < 0.01$) in pellet-fed pigs than in meal-fed pigs, but the magnitude of the difference was likely not great enough to negatively affect drop credit of stomachs. In conclusion, feeding pelleted diets improved growth performance and increased carcass weight and fatness without causing the development of gastric lesions that would reduce the value of the stomach to packers. Furthermore, inclusion of DDGS in diets reduced HCW and dressing percent and increased GI tract and GI tract contents weight but had no effect on gastric lesion development or LM quality.

Key words: diet form, distillers' dried grains with solubles, morphology, pellet, pig, ulcer

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INTRODUCTION

Pelleting swine diets is a technology used by the feed milling industry where a meal diet is subjected to heat and/or moisture and then pressed through a die to agglomerate smaller particles into a larger composite (Hancock and Behnke, 2001). Feeding pelleted diets improved nutrient digestibility (Wondra et al., 1995; Rojas, 2015) and feed efficiency (Wondra et al., 1995; Nemechek et al., 2015) and, in some experiments, increased rate of gain (Wondra et al., 1995; Myers et al., 2013; Nemechek et al., 2015). Results of several experiments indicated that there is no effect of diet form on carcass characteristics

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Table 1. Ingredient composition of experimental diets for growing–finishing pigs

	Phase 1: Grower				Phase 2: Early finisher				Phase 3: Late finisher			
	Meal		Pellet		Meal		Pellet		Meal		Pellet	
	DDGS[1]											
Ingredient, %	0%	30%	0%	30%	0%	30%	0%	30%	0%	30%	0%	30%
Corn	71.98	47.00	71.98	47.00	78.36	54.68	78.36	54.68	80.87	58.90	80.87	58.90
Soybean meal, 48% CP	22.00	17.30	22.00	17.30	18.20	12.00	18.20	12.00	16.00	8.00	16.00	8.00
DDGS	–	30.00	–	30.00	–	30.00	–	30.00	–	30.00	–	30.00
Choice white grease	2.00	2.00	2.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Limestone	0.85	1.15	0.85	1.15	0.80	1.10	0.80	1.10	0.70	1.05	0.70	1.05
Dicalcium P	1.10	0.60	1.10	0.60	0.80	0.35	0.80	0.35	0.70	0.20	0.70	0.20
L-Lys HCl	0.34	0.35	0.34	0.35	0.21	0.27	0.21	0.27	0.13	0.25	0.13	0.25
DL-Met	0.04	–	0.04	–	–	–	–	–	–	–	–	–
L-Thr	0.09	–	0.09	–	0.03	–	0.03	–	–	–	–	–
Salt	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Micromineral premix[2]	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Tylan[4]	1.00	1.00	1.00	1.00	–	–	–	–	–	–	–	–
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

[1]DDGS = distillers' dried grains with solubles.

[2]Provided the following quantities of microminerals per kilogram of complete diet: 20 mg Cu as copper sulfate and copper chloride, 126 mg Fe as ferrous sulfate, 1.26 mg I as ethylenediamine dihydroiodide, 60.2 mg Mn as manganese sulfate, 0.3 mg Se as sodium selenite and selenium yeast, and 125.1 mg Zn as zinc sulfate.

[3]Provided the following quantities of vitamins per kilogram of complete diet: 11,136 IU vitamin A as retinyl acetate, 2,208 IU vitamin D_3 as cholecalciferol, 66 IU vitamin E as DL-alpha tocopheryl acetate, 1.42 mg vitamin K as menadione dimethylprimidinol bisulfite, 0.24 mg thiamin as thiamine mononitrate, 6.59 riboflavin, 0.24 pyridoxine as pyridoxine hydrochloride, 0.03 mg vitamin B_{12}, 23.5 mg d-pantothenic acid as d-calcium pantothenate, 44.1 mg niacin, 1.59 mg folic acid, and 0.44 mg biotin.

[4]Provided 100 mg/kg of tylosin phosphate per kilogram of complete feed(Elanco Animal Health, Greenfield, IN).

(Wondra et al., 1995; Myers et al., 2013; Nemechek et al., 2015); however, others have reported increased dressing percent (Fry et al., 2012), backfat, and belly fat (Matthews et al., 2014) of pigs fed pelleted diets. Pigs fed pelleted diets have a greater instance and severity of gastric lesions than meal-fed pigs (Gamble et al., 1967; Wondra et al., 1995), but the effects of pelleting diets containing 30% distillers' dried grains with solubles (**DDGS**) on stomach morphology or the effect of pelleting alone on gastrointestinal (**GI**) tract traits are largely unknown. Therefore, the objective of this experiment was to determine the effects of feeding pelleted diets without or with DDGS on carcass characteristics and GI weights of growing–finishing pigs to explain previously reported differences in dressing percent.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocol for this experiment.

Experimental Design and Dietary Treatments

A total of 192 barrows and gilts, from the mating of G-performer boars mated to Fertilis-25 females (Genetiporc USA LLC, Alexandria, MN) were blocked by age and stratified within both blocks by initial BW (25.7 ± 2.29 kg). Within each block, 6 pens (2 barrows and 2 gilts per pen) were randomly assigned 1 of 4 treatment combinations in a 2 × 2 factorial arrangement, with 2 diet forms (meal vs. pellet) and 2 DDGS inclusion levels (0 vs. 30).

Pigs were housed in a mechanically ventilated building with partially slatted concrete floors for the entire feeding period. Each 2.59- by 1.83-m pen (1.18 m^2/pig) had a single-space, dry-box feeder mounted on the front gate and a nipple drinker. The thermostat was set at 18.4°C for the entire feeding period and ambient temperature was maintained using thermostatically controlled heaters and fan ventilation. A 3-phase, 91-d feeding program (Tables 1 to 4) was used with grower, early finisher, and late finisher diets fed from d 0 to 35, d 36 to 70, and d 71 to 91, respectively. All diets were formulated based on values for the standardized total tract digestibility of P, standardized ileal digestibility of AA, and NE to meet nutrient requirements for growing–finishing pigs (NRC, 2012). Pigs were weighed at the beginning of the feeding period (d 0) and at the end of each feeding phase. Daily feed allotments were recorded, and data were summarized to calculate ADG, ADFI, and G:F for each pen and phase as well as across the entire 91-d feeding period. Samples of pel-

Table 2. Chemical composition and physical characteristics of grower diets (d 0 to 35), as fed

	Diet form					
	Meal		Before pelleting		Pellet	
	DDGS[1]					
Item	0%	30%	0%	30%	0%	30%
Analyzed composition						
ME,[2] kcal/kg	3,396	3,178	3,320	3,185	3,237	3,219
DM, %	87.60	87.80	86.55	87.23	86.72	86.89
CP, %	16.81	20.76	16.51	21.11	16.68	20.51
Ash, %	3.92	5.01	3.79	4.70	4.37	4.73
AEE,[3] %	4.81	5.29	4.47	4.65	4.06	4.64
ADF, %	3.07	5.08	3.81	5.08	3.75	4.15
NDF, %	8.08	13.35	8.84	12.66	9.45	11.03
Ca, %	0.57	0.50	0.58	0.63	0.75	0.66
P, %	0.50	0.58	0.53	0.58	0.59	0.62
Indispensable AA, %						
Arg	1.07	1.07	1.00	1.05	0.96	1.08
His	0.45	0.52	0.42	0.52	0.41	0.52
Ile	0.74	0.79	0.68	0.82	0.63	0.81
Leu	1.53	2.02	1.44	2.10	1.36	2.08
Lys	1.19	1.16	1.18	1.12	1.02	1.06
Met	0.28	0.32	0.27	0.32	0.26	0.33
Phe	0.87	0.99	0.80	1.02	0.76	1.02
Thr	0.73	0.75	0.70	0.75	0.64	0.80
Trp	0.22	0.21	0.21	0.19	0.21	0.21
Val	0.78	0.90	0.72	0.92	0.68	0.91
Dispensable AA, %						
Ala	0.89	1.19	0.83	1.22	0.81	1.21
Asp	1.72	1.70	1.57	1.69	1.46	1.73
Cys	0.27	0.34	0.26	0.34	0.26	0.35
Glu	3.01	3.29	2.76	3.32	2.73	3.35
Gly	0.73	0.80	0.66	0.79	0.66	0.80
Pro	1.02	1.38	0.97	1.42	0.95	1.41
Ser	0.77	0.86	0.71	0.84	0.69	0.86
Tyr	0.56	0.68	0.53	0.70	0.51	0.69
Total AA	16.83	18.97	15.71	19.13	15.00	19.22
Physical characteristics						
Mean particle size, µm	780.0	480.0	826.0	661.0	–	–
SD of particle size	2.1	2.0	2.0	1.9	–	–
SA,[4] cm^2/g	75.7	133.8	69.3	85.6	–	–
Angle of repose, °	34.3	31.3	–	–	17.0	16.6
Bulk density, g/L	693.0	656.0	–	–	746.0	715.0

[1]DDGS = distillers' dried grains with solubles.

[2]ME values were calculated (NRC, 2012).

[3]AEE = acid-hydrolyzed ether extract.

[4]SA = surface area of particle.

leted diets (before and after pelleting) and meal diets were collected from each batch within each phase for chemical and physical analyses. The heaviest barrow and gilt from each pen were removed for slaughter on d 91, whereas the remaining pigs were slaughtered 2 d later. Gastrointestinal tract organ weights were collected from pigs in the first slaughter group, but carcass characteristics and LM loin quality were evaluated on carcasses from both slaughter groups.

Diet Analyses

Diets were analyzed for DM (method 930.15; Hortwitz and Latimer, 2007), ash (method 942.05; Hortwitz and Latimer, 2007), GE using bomb calorimetry (model 6300; Parr Instrument Company, Moline, IL), and CP by combustion (method 999.03; Hortwitz and Latimer, 2007) on a Rapid N cube (Elementar Americas Inc., Mt. Laurel, NJ). Acid-hydrolyzed ether extract was determined by acid hydrolysis using 3 *N HCl (*Sanderson,

Table 3. Chemical composition and physical characteristics of early finisher diets (d 36 to 70), as fed

	Diet form					
	Meal		Before pelleting		Pellet	
	DDGS[1]					
Item	0%	30%	0%	30%	0%	30%
Analyzed composition						
ME,[2] kcal/kg	3,273	3,185	3,293	3,098	3,323	3,229
DM, %	86.57	86.81	86.84	86.06	86.06	86.50
CP, %	14.05	18.02	13.84	17.81	14.01	17.96
Ash, %	3.24	3.81	3.49	3.91	3.58	4.16
AEE,[3] %	3.70	5.10	3.45	4.88	3.86	5.25
ADF, %	3.94	6.11	3.31	6.47	3.09	5.11
NDF, %	10.06	14.13	8.79	15.16	7.29	11.72
Ca, %	0.44	0.50	0.53	0.50	0.55	0.57
P, %	0.42	0.50	0.43	0.51	0.45	0.50
Indispensable AA, %						
Arg	0.76	0.94	0.79	0.94	0.82	0.97
His	0.34	0.47	0.35	0.48	0.36	0.48
Ile	0.52	0.71	0.54	0.71	0.56	0.74
Leu	1.17	1.84	1.22	1.84	1.27	1.89
Lys	0.81	0.95	0.82	0.96	0.84	0.98
Met	0.20	0.30	0.21	0.31	0.20	0.30
Phe	0.63	0.89	0.65	0.89	0.68	0.91
Thr	0.51	0.68	0.52	0.68	0.53	0.69
Trp	0.17	0.17	0.18	0.18	0.18	0.18
Val	0.56	0.82	0.59	0.82	0.62	0.84
Dispensable AA, %						
Ala	0.70	1.09	0.72	1.08	0.74	1.11
Asp	1.18	1.48	1.22	1.46	1.25	1.52
Cys	0.22	0.30	0.22	0.32	0.22	0.31
Glu	2.20	2.88	2.27	2.79	2.32	2.95
Gly	0.54	0.72	0.55	0.71	0.55	0.95
Pro	0.81	1.24	0.83	1.23	0.86	1.27
Ser	0.58	0.80	0.60	0.78	0.60	0.80
Tyr	0.41	0.61	0.44	0.62	0.46	0.65
Total AA	12.31	16.89	12.72	16.80	13.06	17.54
Physical characteristics						
Mean particle size, μm	443.0	707.0	855.0	726.0	–	–
SD of particle size	2.5	2.0	2.0	2.3	–	–
SA,[4] cm^2/g	209.4	81.6	67.7	89.8	–	–
Angle of repose, °	32.0	30.2	–	–	17.3	18.6
Bulk density, g/L	641.0	617.0	–	–	717.0	673.0

[1]DDGS = distillers' dried grains with solubles.

[2]ME values were calculated (NRC, 2012).

[3]AEE = acid-hydrolyzed ether extract.

[4]SA = surface area of particle.

1986) followed by crude fat extraction using petroleum ether (method 2003.06; Hortwitz and Latimer, 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN). Diets were also analyzed for AA (method 982.20 E [a, b, c]; Hortwitz and Latimer, 2007), ADF (method 973.18; Hortwitz and Latimer, 2007), and NDF (Holst, 1973), whereas P and Ca were analyzed by inductively coupled plasma spectroscopy (method 975.03; Hortwitz and Latimer, 2007) after wet ash sample preparation. Mean particle size and distribution, bulk density, and angle of repose were determined using the procedures described by Rojas (2015), Cromwell et al. (2000), and Appel (1994), respectively.

Slaughter Procedures and Evisceration

The day before slaughter, pigs were transported to the University of Illinois Meat Science Laboratory

Table 4. Chemical composition and physical characteristics of late finisher diets (d 71 to 91), as fed

	Diet form					
	Meal		Before pelleting		Pellet	
			DDGS[1]			
Item	0%	30%	0%	30%	0%	30%
Analyzed composition						
ME,[2] kcal/kg	3,309	3,137	3,335	3,151	3,291	3,201
DM, %	86.49	87.03	86.48	86.93	86.30	86.64
CP, %	13.32	15.46	13.79	16.20	12.93	15.91
Ash, %	3.12	3.78	2.77	3.47	3.42	3.53
AEE,[3] %	3.74	4.80	3.56	5.02	3.52	5.14
ADF, %	3.87	6.08	3.42	6.42	2.94	4.17
NDF, %	9.07	14.77	9.18	15.54	8.23	13.67
Ca, %	0.45	0.46	0.44	0.37	0.52	0.48
P, %	0.43	0.46	0.40	0.45	0.44	0.47
Indispensable AA, %						
Arg	0.76	0.79	0.73	0.79	0.80	0.78
His	0.34	0.42	0.33	0.41	0.35	0.40
Ile	0.53	0.62	0.51	0.60	0.57	0.59
Leu	1.19	1.68	1.15	1.61	1.26	1.60
Lys	0.76	0.82	0.75	0.82	0.83	0.81
Met	0.21	0.28	0.20	0.27	0.21	0.27
Phe	0.64	0.78	0.62	0.76	0.67	0.75
Thr	0.48	0.59	0.47	0.59	0.51	0.58
Trp	0.16	0.16	0.15	0.16	0.16	0.17
Val	0.58	0.73	0.54	0.71	0.61	0.70
Dispensable AA, %						
Ala	0.70	1.00	0.69	0.97	0.73	0.96
Asp	1.18	1.23	1.15	1.23	1.26	1.21
Cys	0.23	0.27	0.22	0.27	0.23	0.28
Glu	2.20	2.52	2.15	2.45	2.33	2.44
Gly	0.53	0.62	0.53	0.62	0.56	0.61
Pro	0.82	1.14	0.79	1.09	0.85	1.08
Ser	0.57	0.70	0.57	0.69	0.60	0.68
Tyr	0.44	0.56	0.41	0.52	0.44	0.55
Total AA	12.32	14.91	11.96	14.56	12.97	14.46
Physical characteristics						
Mean particle size, μm	1,017.0	860.0	1,059.0	947.0	–	–
SD of particle size	1.7	1.9	1.7	1.8	–	–
SA,[4] cm^2/g	52.2	64.5	49.5	56.2	–	–
Angle of repose, °	32.3	31.6	–	–	20.4	22.5
Bulk density, g/L	642.0	599.0	–	–	743.0	681.0

[1]DDGS = distillers' dried grains with solubles.

[2]ME values were calculated (NRC, 2012).

[3]AEE = acid-hydrolyzed ether extract.

[4]SA = surface area of particle.

(Urbana, IL) and held for approximately 16 h in lairage, with ad libitum access to water but not feed. Pigs were weighed at the abattoir, to collect ending live weight (**ELW**), immediately before being humanely slaughtered under USDA Food Safety and Inspection Service supervision. Pigs were immobilized using the head-to-heart electrical stunning technique followed by exsanguination. Full GI tract and GI tract component (esophagus, stomach, small intestine, large intestine, and mesenteric fat) weights were recorded immediately following evisceration according to the procedure described by Boler et al. (2014). The full GI tract was weighed before the large intestine was separated from the small intestine at the ileocecal junction and the small intestine was separated from the stomach between the pyloric sphincter and the duodenum. The stomach was removed from the

esophagus where the esophagus empties into the esophageal region of the stomach. Each section of the GI tract was rinsed with water to remove all digestive and fecal material. Mesenteric tissue surrounding the GI tract was removed and weighed separately. The GI tract contents weight was calculated as the difference between the full GI tract and the sum of the cleaned, separate components, whereas the weight of the GI tract was calculated as the absolute weight and as a percentage of (92-d) ELW.

Stomach Morphology Evaluation

Stomachs were identified with tags corresponding to individual pig identification, placed in cardboard boxes with a liner, and frozen at −20°C following weighing and to evaluate for gastric lesions at a later date. Stomachs were allowed to thaw at 4°C for 72 h before being cut such that the pars esophagea remained intact. Evaluation of gastric lesions in the pars esophagea region of the stomach was conducted by 3 trained panelists using reference images according to the protocol described by Nielsen and Ingvartsen (2000): 0 = normal, 1 = minor parakeratosis, 2 = medium parakeratosis, 3 = severe parakeratosis, 4 = minor gastric lesion or scar, 5 = medium gastric lesion or scar, 6 = severe gastric lesion or scar and/or crater formation surrounding the entire esophageal entrance into stomach, 7 = reduction of pars esophagea to 3 by 6 cm due to scarring and/or contraction of the esophageal opening to a diameter of 10 mm, 8 = reduction of pars esophagea to 2 by 4 cm due to scarring and/or contraction of esophageal opening to a diameter of 7 mm, 9 = reduction of pars esophagea to 1 by 2 cm due to scarring and/or contraction of the esophageal opening to a diameter of 4 mm with a callused esophagus, or 10 = esophageal opening reduced to 2 mm and severe callusing of the esophagus. Scores of the 3 evaluators were averaged and recorded as gastric lesion score.

Carcass Measurements

Hot carcass weight was recorded immediately after the carcasses passed postmortem inspection. Then, after a 24-h chilling period at 4°C, the left side of each carcass was ribbed between the 10th and 11th ribs. Fat depth at the 10th rib was measured perpendicular to the skin three-fourths of the length of the LM, whereas for LM area (**LMA**), the LM was first traced onto double matted acetate paper and LM outlines were subsequently traced in duplicate using a digitizer pad (Intuos Pro Digitizer Tablet and stylus; Wacom Technology Corporation, Vancouver, WA). Area of the LM was then measured using the magic wand tool of Adobe Photoshop CS6 (Adobe Systems Inc., San Jose, CA). The average of the 2 measurements was reported as LMA. In addition, estimated lean was determined using the equation of Burson and Berg (2001): estimated lean, % = [8.588 + (0.465 × HCW, lbs) − (21.896 × BF, in) + (3.005 × LMA, in^2)/HCW, lbs × 100]/HCW, lbs.

Loin Quality

Subjective color, objective color, proximate composition, ultimate pH, drip loss, cook loss, and Warner–Bratzler shear force (**WBSF**) evaluations were conducted by trained University of Illinois personnel. Ultimate pH, objective color, subjective color, and marbling and firmness scores were collected from the cut surface of the LM of the left side of each carcass 30 min after ribbing. Ultimate pH was measured 24 h postmortem using a handheld MPI pH meter fitted with a glass electrode (MPI pH-Meter, Topeka, KS) calibrated to pH 4 and 7. Instrumental color (L*, a*, and b*; CIE, 1978) was recorded using a Minolta CR-400 Chroma meter (Minolta Camera Co., Ltd., Osaka, Japan) using a D_{65} light source and a 0° observer with an aperture size of 8 mm and calibrated using a white tile and was measured once at the center of the LM, taking care to avoid connective tissue and intramuscular fat. Subjective color and marbling scores (NPPC, 1999) and firmness scores (NPPC, 1991) were determined by a single observer. A 7-cm-long section of LM was removed from each carcass posterior to the 10th rib and subsequently cut (from anterior to posterior) into 1) a 2.54-cm-thick chop, trimmed free of all subcutaneous fat and connective tissue, homogenized in a food processor, and analyzed for lipid and moisture content in accordance to the methods of Novakofski et al. (1989); 2) a 1.27-cm-thick chop for drip loss determination following the method described by Boler et al. (2011); and 3) a 2.54-cm-thick chop that was vacuum packaged, aged 13 d at 4°C, and frozen at −20°C for WBSF evaluation at a later date.

Warner–Bratzler Shear Force

Vacuum-packaged chops were allowed to thaw at 4°C for 18 h before analysis, trimmed of excess fat, and weighed before being cooked on a Farberware Open Hearth grill (model 455N; Walter Kidde, Bronx, NY). Chops were flipped once at an internal temperature of 35°C and then cooked until they reached an internal temperature of 70°C. Internal temperature was monitored using copper-constantan thermocouples (Type T; Omega Engineering, Stamford, CT) connected to a digital scanning thermometer (model 92000-00; Barnant Co., Barrington, IL). Chops were then cooled to 25°C and weighed before four 1.25-cm-diameter cores were removed parallel to the orientation of the muscle fibers. Cores were then sheared once through the center using a Texture Analyzer TA.HD

Plus (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems Ltd., Godalming, UK) with a blade speed of 3.3 mm/s and a 100-kg load cell. Shear force was reported as the average peak force of the 4 cores. Cooking loss was calculated as the difference between the pre- and postcooked chop weights divided by the precooked chop weight (Boler et al., 2011).

Statistical Analyses

Data were analyzed as a randomized complete block design, with treatments in a 2 × 2 factorial arrangement and pen as the experimental unit. The ANOVA was generated with the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC), with fixed effects of diet form (pellet vs. meal), DDGS inclusion level (0 vs. 30%), and the interactive effect of diet form and DDGS inclusion (12 replicates of each treatment combination) and the random effects of block and replication nested within block. Assumptions of ANOVA were tested with Levene's test and the Brown–Forsythe test for homogeneity of variance. Normality of residuals was tested using the UNIVARIATE procedure of SAS. Least squares means for main and interactive effects were separated with the PDIFF option at $P \leq 0.05$. Main effects and interactions were considered significant at $P \leq 0.05$. Distributions of stomach morphology scores were analyzed using the FREQ procedure of SAS, and Fisher's exact test was used to account for the small sample size and instances where there were less than 5 observations in a category (distributions were considered different at $P \leq 0.05$).

RESULTS AND DISCUSSION

Chemical and Physical Analysis of Diets

All diets were formulated to meet or exceed the nutrient requirements of growing–finishing pigs (Table 1). Chemical and physical traits of the experimental diets through each phase are presented in Tables 2, 3, and 4.

Growth Performance

There were no interactive effects ($P \geq 0.34$) of diet form and DDGS inclusion during the grower phase (d 0 to 35) for any growth performance traits (Table 5). There was no effect of diet form on ADG ($P = 0.21$), ADFI ($P = 0.51$), or BW ($P = 0.28$); however, pigs fed pelleted diets had 3.2% greater ($P < 0.01$) G:F than meal-fed pigs. In addition, feeding diets with 30% DDGS reduced ($P \leq 0.03$) ADG by 3.2%, ADFI by 3.5%, and d-35 BW by 1.47 kg compared with feeding diets with 0% DDGS.

During the early-finishing phase (d 36 to 70), pigs fed pelleted diets had 3.4% greater ($P = 0.03$) ADG compared with pigs fed meal diets, but there was no effect ($P = 0.50$) of DDGS inclusion on ADG (Table 5). In meal-fed pigs, inclusion of 30% DDGS increased ($P = 0.01$) ADFI by 0.14 kg (5.0%) compared with pigs fed no DDGS, but ADFI was not different between DDGS levels in pellet-fed pigs (diet form × DDGS inclusion, $P < 0.01$). Moreover, for pigs fed 30% DDGS, pelleting increased ($P < 0.01$) G:F by 7.8%, but there was no effect ($P = 0.32$) of pelleting on G:F in pigs fed 0% DDGS (diet form × DDGS inclusion, $P = 0.03$). At the end of the early-finishing phase, BW was not affected by either diet form ($P = 0.12$) or DDGS inclusion ($P = 0.09$).

During the late-finishing phase (d 71 to 91), feeding pelleted diets increased ($P = 0.01$) ADG by 0.06 kg (6.4%) compared with feeding meal diets, but ADG was not affected ($P = 0.46$) by DDGS inclusion (Table 5). Among meal-fed pigs, 30% inclusion of DDGS increased ($P < 0.01$) ADFI by 0.26 kg (8.4%), but ADFI was not different ($P \geq 0.47$) between pigs fed 0 and 30% DDGS pelleted diets (diet form × DDGS inclusion, $P = 0.02$). Moreover, pellet-fed pigs had 9.2% greater ($P < 0.01$) G:F than meal-fed pigs and were 2.6% heavier ($P < 0.01$) at the end of the late-finishing phase than meal-fed pigs. However, there was no effect ($P \geq 0.37$) of DDGS inclusion on G:F or BW.

Overall (d 0 to 91), feeding pelleted diets increased ($P < 0.01$) ADG by 3.6%, but there was no effect ($P = 0.46$) of DDGS inclusion on ADG (Table 5). Among meal-fed pigs, diets with 30% DDGS increased ($P < 0.01$) ADFI by 4.7% compared with pigs fed 0% DDGS; however, when 30% DDGS was included in diets, pelleting reduced ($P < 0.01$) overall ADFI by 5.2% (diet form × DDGS inclusion, $P < 0.01$). In addition, pelleted diets increased ($P < 0.0001$) G:F by an average of 5.5%, regardless of DDGS level, whereas feeding no DDGS in meal form increased ($P < 0.01$) G:F over feeding 30% DDGS in meal form (diet form × DDGS inclusion, $P = 0.03$).

The 3.6% improvement in overall ADG due to pelleting is in agreement with the 3 to 4% improvement in ADG reported by Nemechek et al. (2015). Previous research demonstrated a reduction in feed intake when pelleted diets are fed and it has been hypothesized that this decrease in ADFI is due to reduced feed wastage (Skoch et al., 1983; Hancock and Behnke, 2001). In the present experiment, the improvement in ADG of pellet-fed pigs with no difference in ADFI between pellet and meal treatments indicates that improvements in growth performance were due to improved nutrient digestibility of pelleted diets rather than a reduction in feed wastage, which agrees with the results of Seerley et al. (1962a). A number of studies have confirmed that pelleting improves digestibility of starch (Freire et al., 1991; Rojas, 2015), fat (Noblet and van Milgen,

Table 5. Effects of feeding pelleted diets without or with distillers' dried grains with solubles (DDGS) on growth performance

	Meal		Pellet			*P*-value		
	DDGS							
Item	0%	30%	0%	30%	SEM	Diet form	DDGS	Diet form × DDGS
Pen, no.	12	12	12	12				
Initial BW, kg	25.79	25.78	25.68	25.73	0.66	0.07	0.68	0.41
Grower phase(d 0 to 35)								
ADG, kg/d	0.91	0.88	0.94	0.89	0.02	0.21	0.01	0.34
ADFI, kg/d	1.91	1.87	1.92	1.83	0.03	0.51	0.03	0.42
G:F	0.474	0.472	0.491	0.485	0.01	<0.01	0.44	0.68
35-d BW, kg	57.66	56.60	58.61	56.72	0.97	0.28	<0.01	0.41
Early-finisher phase (d 36 to 70)								
ADG, kg/d	0.97	0.99	1.01	1.01	0.01	0.03	0.50	0.36
ADFI, kg/d	2.72^{b}	2.86^{a}	2.80^{ab}	2.71^{b}	0.05	0.40	0.45	<0.01
G:F	0.357^{bc}	0.347^{c}	0.363^{ab}	0.374^{a}	0.01	<0.01	0.90	0.03
70-d BW, kg	91.53	91.19	94.13	91.39	1.31	0.12	0.09	0.18
Late-finisher phase (d 71 to 91)								
ADG, kg/d	0.92	0.97	1.00	1.01	0.03	0.01	0.18	0.46
ADFI, kg/d	3.11^{b}	3.37^{a}	3.14^{b}	3.15^{b}	0.06	0.07	<0.01	0.02
G:F	0.30	0.29	0.32	0.32	0.01	<0.01	0.58	0.36
91-d BW, kg	111.19	111.60	115.31	113.38	1.37	<0.01	0.37	0.17
Overall (d 0 to 91)								
ADG, kg/d	0.94	0.94	0.98	0.96	0.01	<0.01	0.46	0.11
ADFI, kg/d	2.58^{b}	2.70^{a}	2.62^{ab}	2.56^{b}	0.04	0.11	0.25	<0.01
G:F	0.370^{b}	0.360^{c}	0.383^{a}	0.386^{a}	0.01	<0.01	0.27	0.03

$^{a–c}$Least squares means within row lacking a common superscript are different ($P \leq 0.05$).

2004; Xing et al., 2004), and DM, N, and GE (Wondra et al., 1995). Because pigs usually consume feed to meet caloric requirements, improvements in energy digestibility in a diet typically reduce the amount of the diet that will be consumed (NRC, 2012). Improved fat digestibility may also explain the greater reduction in ADFI due to pelleting in pigs fed 30% DDGS compared with pigs fed no DDGS. Conventional DDGS typically contain 9 to 12% crude fat (NRC, 2012), and, because the diets containing 30% DDGS had a greater concentration of fat, improved digestibility of fat due to pelleting may have improved the content of digestible energy. The improvement in G:F for pigs fed pelleted diets is in agreement with the results of previous studies investigating the effects of pelleting diets (Baird, 1973; Wondra et al., 1995; Nemechek et al., 2015). Even though some studies have reported no effect of feeding DDGS on G:F (Hill et al., 2008; Xu et al., 2010; McDonnell et al., 2011), other experiments have observed that feeding 30% DDGS reduced G:F compared with feeding diets containing lesser levels of DDGS (Gaines et al., 2007; Asmus et al., 2014). The improved G:F with pelleting diets with 30% DDGS observed in the present experiment indicated that negative effects of feeding coproducts, such as DDGS, may be ameliorated with pelleting, which is in agreement with the observations by Fry et al. (2012).

Gastrointestinal Weights and Stomach Morphology

This appears to be the first experiment to measure the effects of pelleting on the weight of the full GI tract and individual GI tract components. Weight of the full GI tract of pellet-fed pigs was 0.33 percentage units less ($P = 0.03$) of ELW than that of meal-fed pigs, which was mainly due to the 0.39 percentage units of ELW difference ($P < 0.01$) in GI tract contents between pellet-fed pigs and meal-fed pigs (Table 6). Pelleted diets pass more rapidly through the alimentary canal than meal diets (Seerley et al., 1962b). Therefore, a greater amount of the GI tract contents may have been excreted during the lairage period, but the difference in GI tract contents may also have been due to the increased digestibility of DM of pelleted diets (Wondra et al., 1995). The weight and weight as a percentage of ELW of esophagi from pigs fed meal diets containing 30% DDGS were 0.01 and 0.01 percentage units less ($P \leq 0.01$), respectively, than esophagi from pigs fed any other treatment, but there were no differences ($P \geq 0.34$) among the other 3 treatments (diet form × DDGS inclusion, $P \leq 0.02$; interactive results not shown). There were no differences in small intestine or large intestine weights between pigs fed meal diets and pigs fed pelleted diets ($P \geq 0.31$) and there was no effect of diet form on the weight as a percentage of ELW of the stomach or total intestinal

Table 6. Effects of diet form and distillers' dried grains with solubles (DDGS) on gastrointestinal (GI) tract organ weights and weights expressed as a percentage of ending live weight[1]

	Diet form			DDGS			*P*-value		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet form	DDGS	Diet form × DDGS
Pen, no.	24	24		24	24				
Full GI tract,[2] kg	7.65	7.42	0.11	7.37	7.70	0.11	0.14	0.03	0.08
Full GI tract, %	6.79	6.46	0.11	6.41	6.84	0.11	0.03	<0.01	0.18
Esophagus, kg	0.07	0.08	0.002	0.07	0.08	0.002	0.02	0.23	0.01
Esophagus, %	0.06	0.07	0.002	0.06	0.07	0.002	0.08	0.05	0.02
Stomach, kg	0.63	0.61	0.01	0.61	0.62	0.01	0.25	0.36	0.66
Stomach, %	0.55	0.53	0.01	0.53	0.55	0.01	0.07	0.10	0.51
Small intestine, kg	1.50	1.53	0.03	1.51	1.52	0.03	0.57	0.86	0.37
Small intestine, %	1.34	1.33	0.03	1.32	1.35	0.03	0.87	0.39	0.27
Large intestine, kg	1.73	1.72	0.03	1.64	1.80	0.03	0.81	<0.01	0.17
Large intestine, %	1.54	1.49	0.03	1.43	1.60	0.03	0.31	<0.01	0.27
Empty intestine,[3] kg	3.24	3.25	0.05	3.17	3.33	0.06	0.94	0.02	0.42
Empty intestine, %	2.88	2.83	0.04	2.76	2.95	0.04	0.41	<0.01	0.62
Mesenteric fat, kg	1.68	1.83	0.05	1.77	1.74	0.05	0.02	0.75	0.06
Mesenteric fat, %	1.49	1.59	0.04	1.53	1.55	0.04	0.07	0.86	0.08
GI tract contents,[4] kg	2.07	1.66	0.07	1.75	1.98	0.07	<0.01	0.02	0.19
GI tract contents, %	1.84	1.45	0.07	1.53	1.77	0.07	<0.01	0.01	0.24
Gastric lesion score[5]	1.27	1.79	0.12	1.40	1.67	0.12	<0.01	0.10	0.44

[1]Organ weight as a percentage of ending live weight was calculated as organ, % = (organ, kg/ending live weight, kg) × 100.

[2]Full GI tract = weight of the full GI tract including esophagus, stomach, small intestine, large intestine, mesenteric fat, and the contents of all organs.

[3]Intestinal weight = small intestine weight + large intestine weight.

[4]GI tract contents, kg = full GI tract − (esophagus + stomach + small intestine + large intestine + mesenteric fat).

[5]Gastric lesion scores were rated on a 10 point scale where 0 represents a normal stomach with no evidence of ulceration and 10 represented an esophageal opening reduced to 2 mm and severe callusing of the esophagus.

mass ($P \geq 0.07$). Pellet-fed pigs also had greater ($P = 0.02$) mesenteric fat weights than meal-fed pigs, but mesenteric fat weight as a percentage of ELW was not affected ($P = 0.07$) by diet form.

As expected, DDGS inclusion increased ($P \leq 0.03$) full GI tract weight, large intestine weight, total intestinal weight, and GI tract contents in terms of absolute weight and as a percentage of ELW (Table 6). An increase in large intestine weight due to increase in dietary fiber has been observed in previous studies (Jørgensen et al., 1996; Agyekum et al., 2012), with the increase in digestive organ mass in being attributed to hypertrophic growth due to increased peristaltic action as well as increased capacity to secrete digestive fluids (Agyekum et al., 2012).

The incidence and severity of gastric ulcers in pigs is a concern to the pork industry due to increased pig death on the farm and decreased drop credit (value of the noncarcass components) for packers, due to discounts on stomachs. In the present experiment, pigs fed pelleted diets had greater ($P < 0.01$) gastric lesion scores of the esophageal region of the stomach compared with meal-fed pigs (Table 6), which is in agreement with the results of previous experiments (Gamble et al., 1967; Wondra et al., 1995; Nielsen and Ingvartsen, 2000). The difference in mean gastric lesion scores between diet forms is further substantiated by the difference in the distributions of scores (Fisher's exact test, *P < 0.01;* Fig. 1). Of the 48 meal-fed pigs, 68.8% of stomachs were scored as normal (0 on a scale of 0 to 10) or as displaying minor parakeratosis (1 on a scale of 0 to 10) compared with only 34% of the stomachs of pellet-fed pigs falling within the same scores. There was no incidence of ulcers in meal-fed pigs, but 4.3% of the

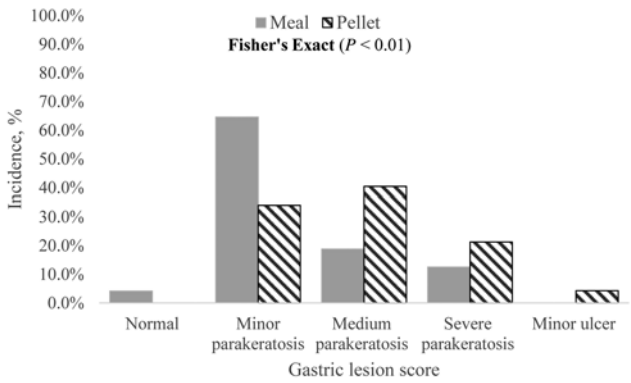

Figure 1. Distributions of stomach morphology scores were analyzed as a Fisher's exact test to account for the small sample size and instances where there were less than 5 observations in a category. Data presented are frequency distributions for the occurrence of gastric lesion scores (0 = normal, 1 = minor parakeratosis, 2 = medium parakeratosis, 3 = severe parakeratosis, and 4 = minor gastric lesion or scar) of pigs fed meal or pelleted diets. Distributions were considered different at $P \leq 0.05$.

Table 7. Effects of feeding diet form and distillers' dried grains with solubles (DDGS) on carcass characteristics

	Diet form			DDGS			*P*-value		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet form	DDGS	Diet form × DDGS
Pen, no.	24	24		24	24				
Ending live wt, kg	110.50	113.06	1.30	112.65	110.91	1.30	<0.01	0.06	0.11
HCW, kg	86.34	88.84	1.12	88.65	86.54	1.12	0.01	0.01	0.17
Dressing percent	78.11	78.56	0.14	78.66	78.00	0.14	0.02	<0.01	0.78
Loin muscle area, cm^2	49.49	49.65	0.75	50.41	48.73	0.75	0.84	0.04	0.71
10th-rib fat depth, cm	1.63	1.80	0.04	1.74	1.70	0.04	0.01	0.40	0.08
Estimated carcass lean,[1] %	56.70	54.91	0.59	56.25	55.36	0.59	0.04	0.30	0.10

[1]Estimated carcass lean percentage = {[8.588 + (0.465 × HCW, lb) − (21.896 × 10th-rib fat depth, in) + (3.005 × 10th-rib LMA, in^2)]/HCW} × 100 (Burson and Berg, 2001).

pellet-fed pigs had minor ulceration (4 on a scale of 0 to 10). There was no difference ($P = 0.10$) in gastric lesion scores nor was there a difference ($P = 0.12$; results not shown) in the distribution of scores between pigs fed 0% DDGS and pigs fed 30% DDGS. Although differences in gastric lesion scores and distributions were statistically different, the relatively small magnitude of difference was not likely substantial enough to negatively affect the drop credit value of the stomach or pig growth performance; in fact, pellet-fed pigs grew faster and more efficiently than meal-fed pigs.

Carcass Characteristics and Loin Quality

There were no interactions ($P \geq 0.08$) *of diet form and DDGS inclusion level on carcass characteristics (*Table 7). Pigs fed pelleted diets had 2.9% heavier ($P = 0.01$) HCW and 0.45 percentage units greater ($P = 0.02$) dressing percent than meal-fed pigs. The difference in HCW may be due to increased fat deposition, as carcasses of pellet-fed pigs had 0.16 cm greater ($P < 0.01$) fat depth at the 10th rib than carcasses from meal-fed pigs, but LMA did not differ ($P = 0.84$) between carcasses from pellet-fed pigs and carcasses from meal-fed pigs. Therefore, the greater dressing percent of pellet-fed pigs was largely due to the combination of decreased GI tract contents and increased fat thickness. The combination of greater HCW and increased fat thickness resulted in carcasses of pellet-fed pigs having 1.79 percentage units less ($P = 0.04$) estimated carcass lean percentage than carcasses from meal-fed pigs. Hot carcass weight of pigs fed 30% DDGS was 2.11 kg less ($P = 0.01$) and the resulting dressing percent was 0.66 percentage units less ($P < 0.01$) than that of pigs fed 0% DDGS. In addition, carcasses from pigs fed 30% DDGS had 1.69 cm^2 smaller ($P = 0.04$) LMA than carcasses from pigs fed 0% DDGS, which agrees with previous work indicating a decrease in LM depth in pigs fed a 30% DDGS diet vs. pigs fed a 0% DDGS diet (Whitney et al., 2006). The decrease in dressing percent of pigs fed 30% DDGS was expected, as these pigs had increased full GI tract weight, with proportionally heavier large intestines than pigs fed 0% DDGS. Neither 10th-rib fat depth ($P = 0.40$) nor estimated carcass lean percentage ($P = 0.30$) were affected by DDGS inclusion, which is in agreement with results of Leick et al. (2010). Previous research has reported that there was no effect of diet form on pork carcass characteristics (Wondra et al., 1995; Myers et al., 2013**,** Nemechek et al., 2015); however, others have reported that feeding pelleted diets increased dressing percent (Fry et al., 2012), backfat depth, and belly fatness (Matthews et al., 2014). These contrasting results may be due to differences in market weights. Wondra et al. (1995) slaughtered pigs when the heaviest pen in each block weighed 114 kg and observed no effect of diet form on backfat depth or dressing percent, whereas Fry et al. (2012) slaughtered pigs when the mean weight was approximately 130 kg and demonstrated that feeding pelleted diets increased dressing percent. Because pelleting increased rate of passage (Seerley et al., 1962b), it is likely that pellet-fed pigs excreted a greater amount of GI tract contents during transport and lairage than meal-fed pigs, which is indicated by pellet-fed pigs having decreased GI tract contents as a percentage of ELW. Studies in which ending farm weight were used to calculate dressing percent (Myers et al., 2013; Nemechek et al., 2015) do not take into account weight loss during transport and lairage, which can account for a loss of approximately 3% of BW (Boler et al., 2014). Increased carcass fatness was expected with increased starch (Freire et al., 1991; Rojas, 2015) and fat digestibility (Noblet and van Milgen, 2004; Xing et al., 2004), because with more digested energy would result in more energy available for fat deposition.

There were no interactions ($P \geq 0.23$) of diet form and DDGS inclusion on any loin quality traits (Table 8). There was no effect ($P \geq 0.07$) of diet form on subjective LM color or instrumental color values. Even though the LM from carcasses of pellet-fed pigs had less ($P = 0.03$) moisture than those of meal-fed pigs, there was no effect ($P \geq 0.08$) of diet form on LM pH, drip loss, marbling score, extractable lipid content, firmness score, cooking

Table 8. Effects of diet form and distillers' dried grains with solubles (DDGS) on loin muscle quality

	Diet form			DDGS			*P*-value		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet form	DDGS	Diet form × DDGS
Pen, no.	24	24		24	24				
Color[1]	1.93	1.80	0.05	1.87	1.86	0.05	0.07	0.89	0.48
Marbling[1]	1.32	1.28	0.06	1.31	1.30	0.06	0.70	0.90	0.64
Firmness[2]	1.46	1.55	0.08	1.51	1.49	0.08	0.40	0.83	0.89
L*[3]	50.66	51.32	0.40	51.34	50.63	0.40	0.19	0.16	0.79
a*[3]	8.59	8.34	0.16	8.55	8.38	0.16	0.23	0.38	0.31
b*[3]	4.13	4.16	0.19	4.32	3.97	0.19	0.92	0.15	0.64
Moisture, %	74.52	74.28	0.08	74.23	74.58	0.08	0.03	<0.01	0.88
Lipid, %	2.57	2.77	0.08	2.77	2.71	0.08	0.08	0.52	0.23
Ultimate pH	5.57	5.58	0.01	5.58	5.58	0.01	0.38	0.85	0.61
Drip loss, %	5.67	5.47	0.26	5.63	5.51	0.26	0.55	0.70	0.90
Cook loss, %	24.90	24.51	0.45	24.45	24.96	0.45	0.47	0.35	0.57
WBSF,[4] kg	3.21	3.10	0.07	3.13	3.18	0.07	0.27	0.62	0.57

[1]National Pork Producers Council (1999).

[2]National Pork Producers Council (1991).

[3]L* is a measure of darkness to lightness (a greater L* value indicates a lighter color), a* is a measure of redness (a greater a* value indicates a redder color), and b* is a measure of yellowness (a greater b* value indicates a more yellow color).

[4]WBSF = Warner–Bratzler shear force.

loss, or WBSF values. There is a lack of reported effects of diet form on loin quality, but there are no indications that feeding a pelleted diet should affect the quality characteristics of lean tissue. Furthermore, inclusion of DDGS in diets had no effect ($P \geq 0.15$) on any loin quality traits. This observation is in agreement with previous experiments that failed to discover an effect of feeding up to 30% DDGS did influence on marbling, ultimate pH, objective color, or proximate composition of the LM (Xu et al., 2010; Leick et al., 2010; Lee et al., 2013).

Conclusions

Although the effects of diet form on growth performance and gastric lesion development in growing–finishing pigs has been extensively researched, comprehensive characterization of the effect of diet form on pork carcass characteristics are limited. Moreover, no previous study has evaluated interactive effects of diet form and DDGS inclusion level. The present study demonstrated that pelleting improved growth performance when diets include 30% DDGS; increased HCW and carcass fatness, likely due to increased energy digestibility; and increased dressing percentage due to a reduction in GI tract weight, with no effects on loin quality.

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