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Effects of feeding distillers dried grains with solubles, high-protein distillers dried grains, and corn germ to growing-finishing pigs on pig performance, carcass quality, and the palatability of pork[1]

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ABSTRACT: An experiment was conducted to investigate pig performance, carcass quality, and palatability of pork from pigs fed distillers dried grains with solubles (DDGS), high-protein distillers dried grains (HP-DDG), and corn germ. Eighty-four pigs (initial BW, 22 ± 1.7 kg) were allotted to 7 dietary treatments with 6 replicates per treatment and 2 pigs per pen. Diets were fed for 114 d in a 3-phase program. The control treatment was based on corn and soybean meal. Two treatments were formulated using 10 or 20% DDGS in each phase. Two additional treatments contained HP-DDG in amounts sufficient to substitute for either 50 or 100% of the soybean meal used in the control treatment. An additional 2 treatments contained 5 or 10% corn germ, which was calculated to provide the same amount of fat as 10 or 20% DDGS. Results showed that for the entire experiment, pig performance was not affected by DDGS or HP-DDG, but final BW increased (linear, $P < 0.05$) as corn germ was included in the diets. Carcass composition and muscle quality were not affected by DDGS, but LM area and LM depth decreased (linear, $P < 0.05$) as HP-DDG was added to the diets. Lean meat percentage increased and drip loss decreased as corn germ was included in the diets (quadratic, $P < 0.05$). There was no effect of DDGS on fat quality except that belly firmness decreased (linear, $P < 0.05$) as dietary DDGS concentration increased. Including HP-DDG or corn germ in the diets did not affect fat quality, except that the iodine value increased (linear, $P < 0.05$) in pigs fed HP-DDG diets and decreased (linear, $P < 0.05$) in pigs fed corn germ diets. Cooking loss, shear force, and bacon distortion score were not affected by the inclusion of DDGS, HP-DDG, or corn germ in the diets, and the overall palatability of the bacon and pork chops was not affected by dietary treatment. In conclusion, feeding 20% DDGS or high levels of HP-DDG to growing-finishing pigs did not negatively affect overall pig performance, carcass composition, muscle quality, or palatability but may decrease fat quality. Feeding up to 10% corn germ did not negatively affect pig performance, carcass composition, carcass quality, or pork palatability but increased final BW of the pigs and reduced the iodine value of belly fat.

Key words: corn germ, distillers dried grain with solubles, high-protein distillers dried grain, palatability, performance, pig

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INTRODUCTION

The digestibility of energy, P, and AA in distillers dried grains with solubles (**DDGS**) fed to swine has been reported (Fastinger and Mahan, 2006; Stein et al., 2006b; Pedersen et al., 2007). Growth performance and carcass characteristics have also been measured in growing-finishing pigs fed diets containing different concentrations of DDGS (Whitney et al., 2006), but no data are available on the palatability of pork from pigs fed diets containing DDGS.

The Poet Company (Sioux Falls, SD) has introduced a new biorefining ethanol technology called BFrac that dehulls and degerms the corn before fermentation. Two new coproducts that potentially can be fed to swine are produced from this process. These 2 coproducts are corn germ, originating from degerming of the corn, and high-protein distillers dried grains (**HP-DDG**), which is the distillers dried grains produced after the dehulled and degermed corn has been fermented. Digestibility of AA, P, and energy in these 2 products has been measured (Widmer et al., 2007). However, there

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is no information on pig performance, carcass quality, or palatability of pork from pigs fed diets containing these ingredients. Therefore, the objective of this experiment was to measure performance, carcass quality, and pork palatability of pigs fed diets containing DDGS, HP-DDG, or corn germ.

MATERIALS AND METHODS

Animals and Housing

The Institutional Animal Care and Use Committee at South Dakota State University reviewed and approved the protocol for the experiment.

Eighty-four growing pigs (initial BW, 22.1 ± 1.7 kg) originating from the matings of SP-1 boars to line 13 sows (Ausgene International Inc., Gridley, IL) were allotted to 7 treatments based on BW, ancestry, and sex in a randomized complete block design. Pigs were housed in an environmentally controlled building, with 1 barrow and 1 gilt in each pen and 6 replicate pens per treatment group. Treatments were randomized within the building, and the experiment was conducted from June to November 2006 with 2 replicates initiated on each of 3 different days. Pens (1.2 × 2.4 m) had fully slatted concrete floors, a 1-hole feeder, and a nipple drinker.

Diets, Feeding, and Live Data Recording

Conventional DDGS, HP-DDG, and corn germ were obtained from Poet Nutrition (Sioux Falls, SD). Commercial sources of corn and soybean meal were also used (Tables 1 and 2). Pigs were fed their respective diets in a 3-phase sequence, with a grower diet being provided during the initial 46 d of the experiment, an early finisher diet during the next 40 d, and a late finisher diet during the remaining 28 d. Within each phase, 7 diets were formulated (Tables 3, 4, and 5). The control treatment was based on corn and soybean meal in all 3 phases. Two treatments were formulated using 10 or 20% DDGS in each phase, and 2 additional treatments were formulated by including HP-DDG in amounts sufficient to substitute either 50 or 100% of the soybean meal used in the control treatment in each phase. The diets in which HP-DDG substituted 50% of the soybean meal contained 20, 15, and 10% HP-DDG in the grower, early finisher, and late finisher phases, respectively. The diets in which HP-DDG substituted 100% of the soybean meal contained 40, 30, and 20% HP-DDG in the grower, early finisher, and late finisher phases. The last 2 treatments were formulated using 5 or 10% corn germ in all 3 phases.

Diets were formulated to contain 0.83% standardized ileal digestible (**SID**) Lys and 0.23% apparent total tract digestible (**ATTD**) P in the grower phase, 0.67% SID Lys and 0.19% ATTD P in the early finishing phase, and 0.52% SID Lys and 0.15% ATTD P in the late finishing phase. Calculated concentrations of DE and ME were allowed to vary among diets. Digestibility values for AA, P, and energy in corn and soybean meal were from NRC (1998), but for DDGS, values were obtained from Stein et al. (2006b) and Pedersen et al. (2007). Digestibility values for energy and nutrients in HP-DDG and corn germ were from Widmer et al. (2007). Energy and all nutrients, including vitamins and minerals, were included in all diets to meet or exceed the estimated requirements for growing and finishing pigs (NRC, 1998). Pigs had ad libitum access to feed and water throughout the experiment.

Individual pig BW were recorded at the beginning of the experiment and at the end of each phase. Feed allotments were recorded daily on a pen basis, and feed in the feeders was weighed each time pigs were weighed. Average daily feed intake, ADG, and G:F were calculated for each pen, treatment, and phase and for the entire experimental period at the conclusion of the experiment.

Chemical Analysis of Ingredients and Diets

All samples were analyzed in duplicate. Diets and feed ingredients (corn, soybean meal, DDGS, HP-DDG, and corn germ) were analyzed for DM, CP, crude fat, P, Ca, and AA as previously outlined (Widmer et al., 2007). Diets and ingredients were also analyzed for iodine value (cyclohexane method, procedure Cd 1b-87; AOCS, 2004), and ingredients were analyzed for fatty acid composition (Sukhija and Palmquist, 1988).

Carcass Evaluation

Pigs were slaughtered on 3 d in the same order as which they began the experiment, and all replications were fed experimental diets for 114 d. Final pig BW and feed left in the feeders were recorded the afternoon before the pigs were slaughtered. These weights were used to calculate ADFI, ADG, and G:F. Pigs were removed from feed and fasted overnight. The next morning, pigs were transported approximately 3 km to the South Dakota State University Meats Laboratory where they were slaughtered and processed within 6 h after arrival, in a randomized order among treatments.

Pigs were electrically stunned to render them unconscious before exsanguination. All slaughter procedures were conducted using standard procedures and were in compliance with guidelines from South Dakota State Meat Inspection. Carcasses were placed in the chiller at 4°C approximately 45 min after stunning. The left side of each carcass was ribbed between the 10th and 11th rib at 24 h postmortem, and LM area, LM depth, and fat thickness were measured at the 10th rib using standard procedures (NPB, 2000). Lean meat percentage for each pig was also calculated (NPB, 2000).

The LM was removed without fat from the left side of each carcass. A 0.635-cm-thick chop was cut from the LM between the 10th and 11th rib. This chop was

Table 1. Analyzed nutrient composition of corn, soybean meal, distillers dried grains with solubles (DDGS), high-protein distillers dried grains (HP-DDG), and corn germ (as-fed basis)[1]

Item	Corn	Soybean meal	DDGS	HP-DDG	Corn germ
DM, %	85.20	87.80	91.40	87.50	90.60
CP, %	6.93	43.95	27.46	42.51	15.56
Crude fat, %	2.24	1.25	9.49	3.01	17.32
Ca, %	0.02	0.48	0.28	0.02	0.01
P, %	0.22	0.66	0.74	0.38	1.31
Iodine value	109.50	107.20	123.90	110.90	120.70
Indispensable AA, %					
Arg	0.32	2.99	1.16	1.50	1.11
His	0.19	1.11	0.73	1.06	0.43
Ile	0.24	1.90	0.99	1.70	0.44
Leu	0.85	3.27	3.06	6.03	1.11
Lys	0.22	2.76	0.88	1.11	0.78
Met	0.18	0.61	0.58	0.89	0.27
Phe	0.34	2.12	1.31	2.46	0.59
Thr	0.25	1.67	1.04	1.56	0.53
Trp	0.05	0.57	0.22	0.27	0.10
Val	0.33	2.06	1.37	2.11	0.74
Dispensable AA, %					
Ala	0.52	1.87	1.83	3.24	0.91
Asp	0.47	4.79	1.71	2.67	1.14
Cys	0.16	0.68	0.61	0.81	0.33
Glu	1.26	7.58	4.01	7.27	2.05
Gly	0.27	1.82	1.03	1.32	0.77
Pro	0.60	2.08	2.10	3.58	0.97
Ser	0.33	1.91	1.18	1.95	0.61
Tyr	0.22	1.60	1.11	2.02	0.43

[1]DDGS, HP-DDG, and corn germ were from Poet Nutrition (Sioux Falls, SD).

cut into small cubes, and a 10-g sample (trimmed of fat and connective tissue) was homogenized with 90 mL of distilled water using a Janke & Kunkel Blender Ultra Turrax T25 (IKA Laborechnik, Staufen, Germany). Ultimate LM pH was measured using a PerPHecT LogR pH Meter Model 330 (Thermo Orion, Beverly, MA) and a Corning pH Electrode Model 476286 (Corning Inc., Corning, NY). Drip loss, purge loss, and subjective color and marbling scores of the LM were measured as previously outlined (Stein et al., 2006a).

Belly firmness was measured on all belly primals with the spareribs removed using the procedures reported by Whitney et al. (2006). Belly temperature was measured immediately before the belly firmness test

Table 2. Analyzed fatty acid composition (% of total fat) of corn, soybean meal, distillers dried grains with solubles (DDGS), high-protein distillers dried grains (HP-DDG), and corn germ (as-fed basis)[1]

Item	Corn	Soybean meal	DDGS	HP-DDG	Corn germ
Caprylic acid, C8:0	0.00	0.12	0.16	0.00	0.00
Myristic acid, C14:0	0.00	0.18	0.00	0.00	0.00
Palmitic acid, C16:0	12.80	14.00	13.40	14.40	11.00
Palmitoleic acid, C16:1	0.14	0.19	0.12	0.19	0.11
Heptadecanoic acid, C17:0	0.00	0.17	0.00	0.00	0.10
Stearic acid, C18:0	2.01	4.62	2.37	2.72	1.90
Oleic acid, C18:1	28.60	16.80	27.00	24.80	26.80
Linoleic acid, C18:2	52.80	50.40	52.80	52.40	57.20
Linolenic acid, C18:3	1.30	9.34	1.38	1.66	1.10
Arachidic acid, C20:0	0.46	0.31	0.45	0.43	0.41
ll-Eicosenoic acid, C20:1	0.36	0.19	0.27	0.29	0.28
Eicosadienoic acid, C20:2	0.00	0.00	0.18	0.00	0.00
Eicosadienoic acid, C20:3	0.00	0.00	0.12	0.31	0.00
Arachidonic acid, C20:4	0.00	0.13	0.00	0.00	0.00
Behenic acid, C22:0	0.18	0.48	0.19	0.19	0.15
Lignoceric acid, C24:0	0.24	0.32	0.27	0.26	0.19
Saturated fat, total	15.60	20.10	16.80	17.80	13.60

[1]DDGS, HP-DDG, and corn germ were from Poet Nutrition (Sioux Falls, SD).

Table 3. Composition of grower diets (as-fed basis)[1]

	Diet						
		DDGS		HP-DDG		Corn germ	
Item	Control	10%	20%	Low	High	5%	10%
Ingredient, %							
Corn	67.15	62.78	58.41	61.03	54.90	66.07	64.96
Soybean meal	28.50	23.90	19.30	14.25	—	25.50	22.50
DDGS	—	10.00	20.00	—	—	—	—
Corn germ	—	—	—	—	—	5.00	10.00
HP-DDG	—	—	—	20.00	40.00	—	—
Soybean oil	2.00	1.00	—	2.00	2.00	1.00	—
Limestone	0.90	0.99	1.07	1.06	1.21	0.93	0.96
Monocalcium phosphate	0.87	0.65	0.44	0.79	0.71	0.85	0.84
L-Lys·HCl	—	0.10	0.20	0.27	0.54	0.07	0.14
L-Thr	—	—	—	—	—	—	0.02
L-Trp	—	—	—	0.02	0.06	—	—
NaCl	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin premix[2]	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Micromineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Energy and nutrients[4]							
ME, kcal/kg	3,371	3,333	3,295	3,636	3,700	3,333	3,295
DM, %	88.40	88.80	88.50	88.80	89.80	88.30	88.40
CP, %	17.19	17.70	17.90	18.85	21.30	16.34	15.34
Crude fat, %	4.55	4.35	3.84	4.73	4.71	4.26	4.31
Ca, %	0.61	0.65	0.63	0.60	0.64	0.65	0.61
P, %	0.51	0.52	0.50	0.46	0.43	0.54	0.58
ADF, %	3.22	3.76	4.29	4.04	4.85	3.31	3.40
NDF, %	8.58	10.20	11.82	10.04	11.51	9.24	9.89
Iodine value	116.3	113.7	115.8	117.2	118.5	116.9	115.4
Indispensable AA, %							
Arg	1.09	1.03	0.96	0.90	0.78	1.06	0.94
His	0.46	0.47	0.47	0.47	0.53	0.45	0.40
Ile	0.75	0.73	0.70	0.69	0.83	0.71	0.60
Leu	1.52	1.64	1.71	2.14	2.86	1.48	1.33
Lys	0.97	0.96	0.98	0.90	1.03	1.01	0.89
Met	0.27	0.29	0.29	0.36	0.41	0.27	0.24
Phe	0.85	0.90	0.84	0.99	1.16	0.83	0.72
Thr	0.64	0.65	0.65	0.70	0.74	0.62	0.56
Trp	0.18	0.18	0.16	0.17	0.17	0.16	0.16
Val	0.80	0.80	0.88	0.81	1.04	0.85	0.75

[1]DDGS = distillers dried grains with solubles; HP-DDG = high-protein distillers dried grains. Distillers dried grains with solubles, HP-DDG, and corn germ were from Poet Nutrition (Sioux Falls, SD).

[2]The vitamin premix provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 6,594 IU as acetate; vitamin D_3, 989 IU as D-activated animal sterol; vitamin E, 33 IU as α tocopherol acetate; vitamin K_3, 2.6 mg as menadione dimethylpyrimidinol bisulfite; thiamin, 2.0 mg as thiamine mononitrate; riboflavin, 5.9 mg; pyridoxine, 2.0 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.026 mg; D-pantothenic acid, 20 mg as calcium pantothenate; niacin, 33 mg; folic acid, 0.66 mg; and biotin, 0.1 mg.

[3]The micromineral premix provided the following quantities of microminerals per kilogram of complete diet: Se, 0.18 mg as sodium selenite; I, 0.22 mg as potassium iodate; Cu, 9.5 mg as copper sulfate; Mn, 26.5 mg as manganese sulfate; Fe, 99 mg as iron sulfate; and Zn, 99 mg as zinc oxide.

[4]Values for ME, ADF, and NDF were calculated; all other values were analyzed.

to confirm that all bellies had a similar temperature. Fat samples for analysis of iodine were taken midway between the cranial and caudal ends of the belly at a point just dorsal to the scribe line. Iodine values in these samples were measured as described for the diets and ingredients. Bellies were frozen at −20°C for palatability testing at a later date.

Shear Force Testing and Evaluation of Palatability

Cooking loss and peak shear force of LM samples were measured as previously outlined (Stein et al., 2006a). Likewise, 2 LM chops (2.54-cm thick) per pig were cooked for palatability testing as described by Stein et al. (2006a). Bellies were allowed to thaw and were injected with a brine that consisted of 0.907 kg of a commercial bacon cure per 3.785 L of water. The bellies were pumped to 112% of the beginning weight using an Inject Star Injector Model BI-72 (Inject Star of the Americas Inc., Brookfield, CT). They were then smoked in a Fessmann single-truck smokehouse (Fessmann LP, Kansas City, MO) for approximately 5 h, with the smokehouse schedule consisting of the following steps: step 1 was 20 min on high smoke with the

Table 4. Composition of early finisher diets (as-fed basis)[1]

Item	Control	DDGS 10%	DDGS 20%	HP-DDG Low	HP-DDG High	Corn germ 5%	Corn germ 10%
Ingredient, %							
Corn	74.36	69.79	65.22	69.88	65.37	73.07	71.78
Soybean meal	21.60	17.20	12.80	10.80	—	18.80	16.00
DDGS	—	10.00	20.00	—	—	—	—
Corn germ	—	—	—	—	—	5.00	10.00
HP-DDG	—	—	—	15.00	30.00	—	—
Soybean oil	2.00	1.00	—	2.00	2.00	1.00	—
Limestone	0.77	0.85	0.94	0.88	1.00	0.80	0.82
Monocalcium phosphate	0.69	0.48	0.27	0.64	0.59	0.68	0.67
L-Lys·HCl	—	0.10	0.19	0.21	0.41	0.07	0.13
L-Thr	—	—	—	—	—	—	0.02
L-Trp	—	—	—	0.01	0.05	—	—
NaCl	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin premix[2]	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Micromineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Energy and nutrients[4]							
ME, kcal/kg	3,398	3,359	3,320	3,522	3,645	3,360	3,321
DM, %	86.60	87.00	87.00	87.60	88.30	87.60	87.60
CP, %	14.78	15.03	16.44	16.10	18.76	13.74	13.80
Crude fat, %	4.00	3.72	3.85	4.56	4.99	4.27	4.23
Ca, %	0.49	0.48	0.55	0.50	0.44	0.51	0.51
P, %	0.42	0.44	0.43	0.42	0.37	0.47	0.53
ADF, %	3.03	3.57	4.11	3.64	4.24	3.12	3.22
NDF, %	8.61	10.23	11.85	9.71	10.80	9.27	14.43
Iodine value	114.4	117.0	117.6	119.0	118.1	117.4	119.0
Indispensable AA, %							
Arg	0.86	0.89	0.83	0.82	0.68	0.79	0.84
His	0.38	0.41	0.42	0.42	0.45	0.35	0.36
Ile	0.56	0.62	0.61	0.63	0.68	0.52	0.48
Leu	1.30	1.48	1.63	1.86	2.40	1.27	1.24
Lys	0.73	0.98	0.83	0.77	0.84	0.72	0.79
Met	0.24	0.26	0.30	0.30	0.37	0.23	0.25
Phe	0.70	0.77	0.79	0.82	0.97	0.65	0.64
Thr	0.54	0.57	0.59	0.61	0.65	0.50	0.55
Trp	0.15	0.14	0.14	0.14	0.16	0.15	0.13
Val	0.71	0.79	0.79	0.81	0.87	0.67	0.65

[1]DDGS = distillers dried grains with solubles; HP-DDG = high-protein distillers dried grains. Distillers dried grains with solubles, HP-DDG, and corn germ were from Poet Nutrition (Sioux Falls, SD).

[2]The vitamin premix provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 6,594 IU as acetate; vitamin D_3, 989 IU as D-activated animal sterol; vitamin E, 33 IU as α tocopherol acetate; vitamin K_3, 2.6 mg as menadione dimethylpyrimidinol bisulfite; thiamin, 2.0 mg as thiamine mononitrate; riboflavin, 5.9 mg; pyridoxine, 2.0 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.026 mg; D-pantothenic acid, 20 mg as calcium pantothenate; niacin, 33 mg; folic acid, 0.66 mg; and biotin, 0.1 mg.

[3]The micromineral premix provided the following quantities of microminerals per kilogram of complete diet: Se, 0.18 mg as sodium selenite; I, 0.22 mg as potassium iodate; Cu, 9.5 mg as copper sulfate; Mn, 26.5 mg as manganese sulfate; Fe, 99 mg as iron sulfate; and Zn, 99 mg as zinc oxide.

[4]Values for ME, ADF, and NDF were calculated; all other values were analyzed.

dry bulb temperature at 54.4°C and with 0% humidity; step 2 was 3 h and 40 min on low smoke with the dry bulb temperature at 57.2°C and with 34% humidity; and step 3 lasted until the bellies reached an internal temperature of 53.3°C on low smoke with a dry bulb temperature of 65.6°C and with 54% humidity. The bellies were removed from the smokehouse and placed in a 1.4°C cooler overnight. The bellies were sliced, and 8 slices were selected from the middle of the belly and were vacuum-packaged and placed in a 1.4°C cooler until taste panels were conducted.

An 8-member, trained sensory panel evaluated the palatability of bacon and pork LM chops according to published guidelines (AMSA, 1995). Fifteen samples were evaluated per session, and 2 sessions were conducted per day. A nonexperimental warm-up sample was used to initiate each session. Panelists were secluded in partitioned booths under red incandescent lights.

Bacon slices were cooked using a microwave oven, and initial testing was conducted to determine the length of time that was required to cook the bacon to

Table 5. Composition of late finisher diets (as-fed basis)[1]

	Diet						
		DDGS		HP-DDG		Corn germ	
Item	Control	10%	20%	Low	High	5%	10%
Ingredient, %							
Corn	81.03	76.66	72.27	78.37	75.71	79.75	78.45
Soybean meal	15.10	10.5	5.90	7.55	—	12.30	9.50
DDGS	—	10.00	20.00	—	—	—	—
Corn germ	—	—	—	—	—	5.00	10.00
HP-DDG	—	—	—	10.00	20.00	—	—
Soybean oil	2.00	1.00	—	2.00	2.00	1.00	—
Limestone	0.77	0.85	0.93	0.84	0.92	0.79	0.82
Monocalcium phosphate	0.52	0.31	0.10	0.49	0.45	0.51	0.50
L-Lys·HCl	—	0.10	0.20	0.15	0.30	0.07	0.13
L-Thr	—	—	—	—	—	—	0.01
L-Trp	—	—	0.02	0.02	0.04	—	0.01
NaCl	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin premix[2]	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Micromineral premix[3]	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Energy and nutrients[4]							
ME, kcal/kg	3,419	3,381	3,343	3,502	3,585	3,381	3,342
DM, %	87.90	87.40	87.70	87.60	86.80	87.20	87.10
CP, %	11.66	12.07	12.59	13.16	13.64	11.89	11.24
Crude fat, %	4.11	3.75	3.57	3.81	4.01	3.64	3.61
Ca, %	0.57	0.51	0.49	0.47	0.52	0.53	0.56
P, %	0.41	0.39	0.38	0.38	0.37	0.45	0.49
ADF, %	2.84	3.38	3.91	3.24	3.63	2.99	3.03
NDF, %	8.64	10.25	11.87	9.37	10.09	9.29	9.95
Iodine value	116.6	119.0	116.5	119.0	120.2	119.0	116.6
Indispensable AA, %							
Arg	0.71	0.65	0.66	0.64	0.53	0.66	0.63
His	0.32	0.33	0.35	0.33	0.33	0.31	0.29
Ile	0.48	0.47	0.47	0.46	0.46	0.44	0.41
Leu	1.13	1.27	1.37	1.42	1.75	1.13	1.06
Lys	0.61	0.57	0.70	0.63	0.60	0.58	0.62
Met	0.20	0.21	0.26	0.24	0.27	0.19	0.19
Phe	0.58	0.59	0.60	0.63	0.68	0.54	0.51
Thr	0.44	0.45	0.49	0.48	0.49	0.43	0.41
Trp	0.13	0.12	0.14	0.13	0.13	0.11	0.13
Val	0.56	0.57	0.63	0.54	0.57	0.54	0.51

[1]DDGS = distillers dried grains with solubles; HP-DDG = high-protein distillers dried grains. Distillers dried grains with solubles, HP-DDG, and corn germ were from Poet Nutrition (Sioux Falls, SD).

[2]The vitamin premix provided the following quantities of vitamins per kilogram of complete diet: vitamin A, 6,594 IU as acetate; vitamin D_3, 989 IU as D-activated animal sterol; vitamin E, 33 IU as α tocopherol acetate; vitamin K_3, 2.6 mg as menadione dimethylpyrimidinol bisulfite; thiamin, 2.0 mg as thiamine mononitrate; riboflavin, 5.9 mg; pyridoxine, 2.0 mg as pyridoxine hydrochloride; vitamin B_{12}, 0.026 mg; D-pantothenic acid, 20 mg as calcium pantothenate; niacin, 33 mg; folic acid, 0.66 mg; and biotin, 0.1 mg.

[3]The micromineral premix provided the following quantities of microminerals per kilogram of complete diet: Se, 0.18 mg as sodium selenite; I, 0.22 mg as potassium iodate; Cu, 9.5 mg as copper sulfate; Mn, 26.5 mg as manganese sulfate; Fe, 99 mg as iron sulfate; and Zn, 99 mg as zinc oxide.

[4]Values for ME, ADF, and NDF were calculated; all other values were analyzed.

yield 37.5% of the raw weight. After cooking, a distortion score for each slice was given on a 5-point scale (5 = the most distortion and 1 = the least distortion). The samples were stored in a 50°C oven until served. All panelists received half of a slice of bacon. The panel evaluated crispiness, tenderness, and bacon flavor intensity on an 8-point scale (8 = extremely crispy, tender, or intense and 1 = extremely soft, tough, or bland). The panel also evaluated fattiness, rancid flavor, piggy flavor, or fishy flavor on a 5-point scale (5 = extremely fatty, rancid, piggy, or fishy and 1 = not fatty, rancid, piggy, or fishy).

Statistical Analysis

Growth performance data were analyzed using the MIXED procedure (Littell et al., 1996; SAS Inst. Inc., Cary, NC). Homogeneity of the variance was verified using the UNIVARIATE procedure of SAS. The residual vs. the predicted plot procedure was used to analyze data for outliers (greater than 2× the SD). Treatment means were calculated using the LSMEANS statement in PROC MIXED. Orthogonal polynomials were used to determine linear and quadratic effects of dietary DDGS, HP-DDG, and corn germ concentrations. Data for pigs fed diets containing DDGS were compared with data for pigs fed corn germ and with data for pigs fed HP-DDG using orthogonal contrasts. The pen was the experimental unit, and an α level of 0.05 was used to assess significance among means.

Data for carcass composition, muscle quality, fat quality, and bacon and pork chop palatability were also analyzed using the MIXED procedure of SAS. Homogeneity of the variance and the analysis for outliers were performed as described for performance data. Treatment means were calculated using the LSMEANS statement in PROC MIXED. Belly firmness was adjusted by using belly thickness as a covariate. Orthogonal polynomials and orthogonal contrasts were used to analyze treatment effects as described for the performance data. The pig was used as the experimental unit for these analyses (Stein et al., 2006a), and an α level of 0.05 was used to assess significance among means.

RESULTS

Pig Performance

One pig on the HP-DDG diet became sick 10 d into the experiment and was removed from the study. All other pigs remained healthy throughout the experiment. There was no difference in initial BW among dietary treatments (Table 6), and there was no difference in ADG, ADFI, G:F, and final BW in any phase or for the entire experiment among pigs fed the control, 10% DDGS, or 20% DDGS diets with the exception that G:F in the late finishing period decreased at 10% inclusion of DDGS and then increased at 20% inclusion (quadratic, $P < 0.05$). In the early finisher phase, a trend (quadratic, $P = 0.06$) for an increase in ADG and final BW was observed as DDGS was included in the diet.

In the grower phase, ADG, ADFI, and final BW decreased (linear, $P < 0.05$) as the concentration of HP-DDG increased in the diet. A trend (linear, $P = 0.10$) for a decrease in G:F was also observed as HP-DDG was included in the grower diets, but no differences were observed in ADG, ADFI, G:F, and final BW in the early finisher, late finisher, or for the entire experimental period among pigs fed the control diet and the 2 HP-DDG-containing diets. A trend for a decrease in final BW in the early finisher phase (linear, $P = 0.07$) and in ADFI for the entire experimental period (linear, $P = 0.08$) was, however, observed, for pigs fed diets containing HP-DDG. A trend (quadratic, $P = 0.06$) for a decrease in G:F was also observed in the early and late finisher phases as the dietary concentration of HP-DDG increased.

No differences were observed among pigs fed the control, 5% corn germ, and 10% corn germ diets for ADFI or G:F in any phase or for the entire experimental period. However, final BW and the ADG in the early finisher phase increased as corn germ was added to the diets (linear, $P < 0.05$). Trends for a linear decrease in G:F in the grower phase ($P = 0.06$) and for a linear increase in final BW in the early finisher phase ($P = 0.08$) were also observed as corn germ was included in the diet. There was also a trend (linear, $P = 0.09$) for pigs to increase ADFI in the late finishing phase as the concentration of corn germ was increased in the diet, and ADG for the entire experimental period tended (linear, $P = 0.06$) to increase as corn germ was added to the diet.

There was no difference between pigs fed the corn germ and DDGS diets for ADG, ADFI, G:F, and final BW in any phase or for the entire experimental period. However, ADG was decreased ($P < 0.05$) for pigs fed HP-DDG-containing diets compared with pigs fed the DDGS-containing diets in the grower phase and for the entire experimental period. In the grower phase, early finisher phase, and the entire experimental period, ADFI was greater ($P < 0.05$) for pigs fed the DDGS diets than for pigs fed the HP-DDG diets, but G:F was greater ($P < 0.05$) for pigs fed the HP-DDG diets in the early finisher phase than for pigs fed the DDGS diets. In the grower and early finisher phases, final BW was greater ($P < 0.05$) for pigs fed the DDGS diets than for pigs fed the HP-DDG diets.

Carcass Composition

Hot carcass weight, dressing percentage, and carcass composition were not affected by the addition of DDGS to the diets (Table 7). Likewise, there was no effect of including HP-DDG in the diets for HCW, dressing percentage, lean meat percentage, or 10th rib backfat. However, there was a decrease (linear, $P < 0.05$) in LM area and LM depth as HP-DDG was added to the diets. Hot carcass weight, dressing percentage, LM area, and LM depth were not affected by the inclusion of corn germ in the diets. There was, however, an increase in lean meat percentage (quadratic, $P < 0.01$) and a trend for a decrease in 10th rib backfat as corn germ was included in the diets (quadratic, $P = 0.052$).

There were no differences between pigs fed HP-DDG and DDGS for any carcass composition traits. Likewise, no differences were observed between pigs fed DDGS and corn germ diets with the exception that lean meat percentage and LM area were greater ($P < 0.05$) for pigs fed corn germ diets than for pigs fed DDGS diets.

Muscle and Fat Quality

For LM marbling, color, L*, a*, drip loss, and purge loss, no effects of including DDGS in the diets were observed. There was a decrease (linear, $P < 0.05$) in LM b* value as the concentration of DDGS in the diet increased, and there was a trend (linear, $P = 0.09$) for an increase in LM pH as the concentration of DDGS increased. Longissimus muscle marbling, color, L*, a*,

Table 6. Performance of growing-finishing pigs fed a control diet or diets containing distillers dried grains with solubles (DDGS), high-protein distillers dried grains (HP-DDG), or corn germ[1]

	Diet							DDGS			HP-DDG			Corn germ[2]		
		DDGS		HP-DDG		Corn germ			*P*-value[3]			*P*-value[3]			*P*-value[3]	
Item	Control	10%	20%	Low	High	5%	10%	SEM	L	Q	SEM	L	Q	SEM	L	Q
Grower period																
Initial BW, kg	22.10	21.85	22.03	22.47	22.65	22.12	22.18	0.487	0.821	0.403	0.513	0.416	0.874	0.416	0.813	0.935
ADG,[4] kg	0.805	0.873	0.828	0.762	0.685	0.837	0.832	0.035	0.653	0.205	0.048	0.005	0.580	0.030	0.381	0.471
ADFI,[4] kg	1.778	1.920	1.888	1.706	1.582	1.869	1.899	0.066	0.180	0.217	0.097	0.028	0.706	0.082	0.136	0.647
G:F, kg/kg	0.454	0.456	0.438	0.445	0.433	0.450	0.438	0.012	0.363	0.496	0.008	0.097	0.873	0.007	0.055	0.508
Final BW,[4] kg	59.15	62.02	60.12	57.52	54.13	60.62	60.45	1.76	0.704	0.291	2.35	0.017	0.576	1.58	0.379	0.520
Early finisher period																
ADG, kg	0.987	1.034	0.971	0.979	0.928	1.005	1.055	0.030	0.622	0.063	0.035	0.255	0.610	0.025	0.045	0.563
ADFI,[4] kg	2.993	3.153	3.038	2.944	2.756	3.046	3.164	0.092	0.734	0.243	0.105	0.127	0.587	0.147	0.425	0.859
G:F,[4] kg/kg	0.330	0.328	0.321	0.353	0.337	0.331	0.342	0.007	0.354	0.743	0.007	0.526	0.056	0.016	0.579	0.774
Final BW,[4] kg	98.60	103.42	98.93	96.68	91.27	100.82	102.67	1.90	0.903	0.064	2.95	0.067	0.583	1.62	0.083	0.922
Late finisher period																
ADG, kg	0.909	0.869	0.929	0.903	0.942	0.899	0.999	0.064	0.778	0.411	0.047	0.535	0.624	0.066	0.240	0.394
ADFI, kg	3.263	3.525	3.144	3.388	3.077	3.305	3.658	0.181	0.648	0.167	0.144	0.375	0.237	0.157	0.094	0.428
G:F, kg/kg	0.280	0.245	0.299	0.267	0.306	0.270	0.275	0.016	0.308	0.012	0.012	0.100	0.058	0.018	0.726	0.596
Final BW, kg	124.07	127.73	124.93	121.98	117.65	126.00	130.62	2.77	0.772	0.228	3.18	0.174	0.777	2.40	0.046	0.651
Entire growing-finishing period																
ADG,[4] kg	0.894	0.929	0.903	0.873	0.833	0.911	0.951	0.023	0.758	0.224	0.025	0.111	0.781	0.019	0.055	0.633
ADFI,[4] kg	2.569	2.747	2.600	2.553	2.361	2.634	2.775	0.078	0.783	0.110	0.078	0.079	0.371	0.093	0.138	0.746
G:F, kg/kg	0.349	0.338	0.348	0.343	0.353	0.346	0.345	0.008	0.944	0.323	0.009	0.755	0.441	0.010	0.743	0.928

[1]Data are means of 6 observations per treatment.
[2]No differences between corn germ and DDGS were observed.
[3]L = linear effect; Q = quadratic effect.
[4]DDGS different from HP-DDG ($P < 0.05$).

Table 7. Carcass composition, muscle quality, and fat quality of pigs fed a control diet or diets containing distillers dried grains with solubles (DDGS), high-protein distillers dried grains (HP-DDG), or corn germ[1]

	Diet							DDGS			HP-DDG[2]			Corn germ		
		DDGS		HP-DDG		Corn germ			P-value[3]			P-value[3]			P-value[3]	
Item	Control	10%	20%	Low	High	5%	10%	SEM	L	Q	SEM	L	Q	SEM	L	Q
Carcass composition																
Live wt, kg	124.0	127.7	124.9	122.0	118.0	126.0	130.6	3.20	0.830	0.360	3.67	0.250	0.830	3.33	0.175	0.742
Hot carcass wt, kg	88.3	91.7	88.7	86.6	82.5	89.6	93.8	2.52	0.907	0.241	2.95	0.180	0.752	2.59	0.145	0.646
Dressing, %	71.1	71.7	71.0	70.8	69.8	71.1	71.8	0.47	0.843	0.225	0.65	0.143	0.629	0.48	0.309	0.530
Lean meat,[4] %	51.3	50.2	51.2	52.9	51.3	53.6	51.8	1.20	0.916	0.320	1.10	0.978	0.111	1.14	0.603	0.009
LM area,[4] cm^2	46.6	45.0	44.7	46.8	40.6	49.0	50.1	2.48	0.511	0.792	1.49	0.008	0.080	2.47	0.179	0.771
LM depth, cm	6.06	5.93	5.76	6.01	5.40	5.95	6.26	0.242	0.250	0.937	0.178	0.022	0.208	0.246	0.449	0.339
10th rib backfat, cm	2.50	2.60	2.40	2.23	2.34	2.11	2.48	0.204	0.687	0.441	0.196	0.522	0.335	0.174	0.932	0.052
Muscle quality																
Marbling[5]	2.17	2.13	2.29	2.21	2.26	2.33	2.25	0.403	0.681	0.693	0.444	0.549	0.991	0.368	0.716	0.530
LM color score[5]	3.38	3.17	3.25	3.13	2.97	3.38	3.17	0.243	0.651	0.544	0.236	0.231	0.863	0.224	0.479	0.680
LM color, L*	59.5	58.7	58.2	60.1	59.8	58.4	58.6	0.92	0.334	0.913	0.89	0.837	0.661	1.21	0.599	0.675
LM color, a*	8.22	7.95	7.97	7.88	7.51	7.73	8.16	0.495	0.648	0.766	0.534	0.209	0.977	0.457	0.916	0.331
LM color, b*	16.69	16.17	15.55	15.95	15.67	15.28	16.20	0.376	0.034	0.904	0.326	0.037	0.567	0.446	0.449	0.050
24-h pH, LM	5.35	5.37	5.43	5.39	5.39	5.41	5.41	0.055	0.093	0.651	0.042	0.260	0.537	0.047	0.194	0.417
48-h drip loss, %	4.04	4.28	3.89	4.34	4.17	2.91	4.42	0.493	0.840	0.603	0.640	0.859	0.726	0.445	0.550	0.025
7-d purge loss, %	3.22	3.29	3.23	3.87	3.02	2.96	3.14	0.439	0.985	0.880	0.483	0.685	0.090	0.410	0.885	0.659
Fat quality																
Fat color,[6] L*	81.6	82.0	80.1	81.4	80.7	81.6	81.9	0.64	0.058	0.069	0.59	0.291	0.713	0.65	0.656	0.829
Fat color,[6] a*	1.71	1.82	1.78	1.47	1.58	1.38	1.52	0.284	0.860	0.819	0.359	0.692	0.558	0.337	0.635	0.498
Fat color,[6] b*	10.43	10.48	11.11	10.73	11.10	10.17	10.69	0.289	0.106	0.417	0.355	0.205	0.942	0.347	0.552	0.307
Belly thickness, cm	4.33	4.66	4.13	4.09	4.17	4.09	4.64	0.248	0.572	0.179	0.204	0.593	0.510	0.201	0.289	0.117
Belly firmness score,[7] degrees	54.0	55.0	40.1	44.9	43.3	49.6	62.1	4.27	0.016	0.080	4.52	0.055	0.412	6.62	0.282	0.201
Adjusted belly firmness score,[8] degrees	53.70	54.0	41.3	45.7	43.4	51.3	60.2	4.43	0.010	0.126	4.36	0.057	0.565	7.38	0.381	0.341
Iodine value[4]	69.8	69.8	72.0	72.0	75.3	69.9	64.7	1.25	0.219	0.489	1.01	0.004	0.656	9.31	0.001	0.025

[1]Data are means of 12 observations per treatment.

[2]No differences between HP-DDG and DDGS were observed.

[3]L = linear effect; Q = quadratic effect.

[4]DDGS different from corn germ ($P < 0.05$).

[5]National Pork Producers Council (NPPC, 1999).

[6]Fat color scores were obtained just cranial to the 10th rib in the second layer of fat, counting from the skin inward.

[7]Belly firmness score = cos − 1{[0.5(L2) − D2]/[0.5(L2)]}, where L = belly length measured on a flat surface and D = the distance between the 2 ends of a suspended belly; greater belly firmness scores indicate firmer bellies.

[8]Belly firmness score adjusted for belly thickness.

pH, and drip loss were not affected by the inclusion of HP-DDG in the diets. However, there was a decrease (linear, $P < 0.05$) in LM b* color as HP-DDG was added to the diet. In addition, there was a trend for an increase in purge loss as HP-DDG was included in the diets (quadratic, $P = 0.09$). There was no effect of corn germ on LM marbling, color, L*, a*, pH, and purge loss. However, drip loss decreased for pigs fed diets containing 5% corn germ but increased for pigs fed diets containing 10% corn germ (quadratic, $P < 0.05$). There was also a trend for a decrease in LM b* as corn germ was included in the diet (quadratic, $P = 0.05$), but no differences in muscle quality traits were observed when pigs fed diets containing DDGS were compared with pigs fed diets containing HP-DDG or corn germ.

There was no effect of DDGS on fat a*, belly thickness, or iodine value, but belly firmness score and adjusted belly firmness score decreased as DDGS was added to the diet (linear, $P < 0.05$). A trend for a decrease in fat L* was also observed as DDGS was added to the diet (linear and quadratic, $P = 0.06$ and 0.07). Fat color (L*, a*, and b*) and belly thickness were not affected by the inclusion of HP-DDG in the diets, but iodine value increased ($P < 0.05$) as HP-DDG was included in the diets. A trend (linear, $P = 0.06$) for a decrease in belly firmness score and adjusted belly firmness score was also observed as HP-DDG was included in the diet. There was no effect of corn germ on fat color (L*, a*, and b*), belly thickness, belly firmness score, and adjusted belly firmness score, but iodine value decreased as corn germ was added to the diet (linear and quadratic, $P < 0.05$). There was no difference between pigs fed diets containing HP-DDG and diets containing DDGS in fat quality. No differences were observed between pigs fed the DDGS and corn germ diets with the exception that iodine value was lower ($P < 0.05$) for pigs fed corn germ diets than for pigs fed DDGS diets (67.3 vs. 70.9).

Palatability

Cooking loss, shear force, and bacon distortion were not affected by the addition of HP-DDG or corn germ to the diets (Table 8). However, there was a tendency for a linear decrease in cooking loss ($P = 0.09$) and in bacon distortion ($P = 0.07$) as DDGS was added to the diet.

The trained taste panelists did not detect any differences in bacon flavor intensity, piggy taste, or fishy taste among the control, 10% DDGS, or 20% DDGS diets. A decrease (linear and quadratic, $P < 0.05$) in bacon tenderness, a trend for a decrease in bacon fattiness and rancid taste (linear, $P = 0.06$ and 0.07, respectively), and a trend for an increase (quadratic, $P = 0.07$) in bacon crispiness was observed as DDGS inclusion in the diet increased. Bacon crispiness, tenderness, flavor intensity, rancid taste, piggy taste, and fishy taste were not affected by the inclusion of HP-DDG in the diets, but there was a trend for an increase in bacon fattiness taste as HP-DDG was added to the diet (quadratic, $P = 0.08$). There was no effect of corn germ on bacon crispiness, flavor intensity, fattiness taste, piggy taste, or fishy taste. A trend for a decrease in bacon tenderness (quadratic, $P = 0.06$) and in rancid taste (linear, $P = 0.08$) was observed as the concentration of corn germ in the diets increased.

Pork chop tenderness decreased as 10% DDGS was included in the diet but increased at the 20% inclusion level (quadratic, $P < 0.05$). The metallic taste of the pork chops increased as 10% DDGS was included in the diet but decreased as 20% was included in the diet (quadratic, $P < 0.05$). There was also a tendency for an increase in pork flavor intensity (linear, $P = 0.08$) and for a decrease in off-flavor intensity ($P = 0.09$) and in total off-flavors as the inclusion of DDGS in the diets increased. There was no effect of DDGS on pork chop juiciness, piggy taste, or other off-flavors.

There was an increase (linear, $P < 0.05$) in pork chop juiciness and a trend (linear, $P = 0.09$) for a decrease in pork chop metallic taste and total off-flavors (linear, $P = 0.07$) as the concentration of HP-DDG increased in the diet. For the remaining pork chop palatability measures, however, no effects of HP-DDG were observed. Likewise, the palatability of pork chops was not affected by the inclusion of corn germ in the diets.

DISCUSSION

The concentrations of CP, crude fat, P, and AA in corn and DDGS correspond with published values (Stein et al., 2006b; Pedersen et al., 2007), and concentrations of CP, crude fat, Ca, P, and AA in HP-DDG and corn germ are consistent with values reported by Widmer et al. (2007). Corn and DDGS had similar fatty acid composition, which indicates that fatty acids are not hydrogenated during fermentation of the corn. The fatty acid profile of HP-DDG is also similar to DDGS, but corn germ has a greater concentration of linoleic acid and a decreased concentration of saturated fatty acids than DDGS, HP-DDG, and corn. This observation is consistent with the profile reported for corn germ meal expeller (INRA-AFZ-INAPG, 2004). Soybean meal has a greater concentration of linolenic acid than corn, which also corresponds with published values (INRA-AFZ-INAPG, 2004).

Pig Performance

Growth performance was not affected by the addition of 10 or 20% DDGS to diets fed to growing-finishing pigs. This observation is in agreement with Cook et al. (2005), DeDecker et al. (2005), and Xu et al. (2007), who reported that the inclusion of up to 30% DDGS in diets fed to growing-finishing pigs had no effect on pig performance. However, Fu et al., (2004), Whitney et al. (2006), and Linneen et al. (2007) included up to 30% DDGS in diets fed to growing-finishing pigs and reported a decrease in pig performance as DDGS concentration increased in the diet. One possible reason

Table 8. Palatability of bacon and pork chops of pigs fed a control diet or diets containing distillers dried grains with solubles (DDGS), high-protein distillers dried grains (HP-DDG), or corn germ[1]

	Diet							DDGS			HP-DDG			Corn germ		
		DDGS		HP-DDG		Corn germ			P-value[2]			P-value[2]			P-value[2]	
Item	Control	10%	20%	Low	High	5%	10%	SEM	L	Q	SEM	L	Q	SEM	L	Q
Cook loss, %	28.6	28.5	26.5	28.9	27.2	27.4	28.0	1.14	0.089	0.333	1.04	0.224	0.273	1.30	0.610	0.381
Shear force, kg	3.55	3.60	3.59	3.46	3.16	3.64	3.64	0.229	0.899	0.904	0.190	0.159	0.671	0.164	0.716	0.824
Bacon distortion[3]	2.42	2.14	1.96	2.17	2.12	2.66	2.38	0.175	0.072	0.833	0.262	0.324	0.688	0.217	0.891	0.224
Bacon palatability																
Crispiness[4]	4.16	3.86	4.64	4.18	4.17	4.35	3.91	0.223	0.124	0.066	0.205	0.887	0.964	0.231	0.385	0.150
Tenderness[4]	5.34	5.55	4.79	5.11	5.18	4.86	5.15	0.191	0.046	0.049	0.185	0.532	0.497	0.207	0.414	0.056
Bacon flavor intensity[4]	5.55	5.72	5.54	5.21	5.83	5.56	5.56	0.192	0.966	0.452	0.234	0.352	0.069	0.213	1.000	1.000
Fattiness taste[5]	2.37	2.40	2.09	2.02	2.26	2.20	2.36	0.114	0.063	0.209	0.134	0.585	0.076	0.128	0.954	0.275
Rancid taste[5]	1.16	1.10	1.06	1.20	1.16	1.10	1.04	0.044	0.071	0.908	0.061	0.988	0.501	0.044	0.076	0.938
Piggy taste[5]	1.08	1.14	1.05	1.20	1.17	1.11	1.16	0.040	0.530	0.124	0.063	0.329	0.382	0.059	0.330	0.809
Fishy taste[5]	1.02	1.00	1.00	1.00	1.00	1.00	1.00	0.009	0.137	0.294	0.009	0.111	0.337	0.009	0.980	0.354
Pork chop palatability																
Tenderness[4]	5.64	4.93	5.51	5.48	6.03	5.36	5.56	0.226	0.696	0.025	0.200	0.101	0.131	0.202	0.772	0.340
Juiciness[4]	4.39	4.39	4.45	4.44	4.85	4.68	4.55	0.189	0.745	0.886	0.222	0.047	0.421	0.232	0.560	0.327
Pork flavor intensity[4]	4.91	5.09	5.23	5.23	5.20	5.00	5.13	0.144	0.078	0.929	0.165	0.147	0.325	0.117	0.127	0.826
Off-flavor intensity[6]	1.32	1.33	1.19	1.24	1.29	1.39	1.36	0.084	0.088	0.314	0.074	0.784	0.451	0.084	0.547	0.498
Metallic taste[7]	0.34	0.58	0.00	0.25	0.00	0.33	0.33	0.171	0.055	0.017	0.134	0.086	0.607	0.167	1.000	1.000
Piggy taste[7]	0.58	0.67	0.42	0.77	0.88	0.73	0.88	0.213	0.584	0.528	0.265	0.326	0.873	0.243	0.321	0.956
Other off-flavors[7]	1.14	0.56	0.67	0.52	0.88	1.09	1.00	0.380	0.180	0.276	0.396	0.524	0.235	0.373	0.836	0.850
Total off-flavors[7]	2.08	1.72	1.08	1.56	1.73	2.16	2.18	0.469	0.072	0.783	0.532	0.599	0.570	0.529	0.868	0.944

[1]Data are means of 12 observations per treatment.
[2]L = linear effect; Q = quadratic effect.
[3]Distortion score: 5 = extremely distorted; 1 = no distortion.
[4]Crispiness, tenderness, flavor intensity, and juiciness score: 8 = extremely crispy, extremely tender, extremely intense flavor, or extremely juicy; 1 = extremely soft, extremely tough, extremely bland, or extremely dry.
[5]Fattiness, rancid flavor, piggy flavor, or fishy flavor score: 5 = extremely fatty, extremely rancid, extremely piggy, or extremely fishy; 1 = not fatty, not rancid, not piggy, or not fishy.
[6]Off-flavor intensity score: 4 = extreme off-flavor; 1 = no off-flavor.
[7]Number of yes responses for off-flavor per 8-member panel.

for these conflicting observations may be that different qualities of DDGS were used. The digestibility of AA varies among sources of DDGS (Fastinger and Mahan, 2006; Stein et al., 2006b), and if a source of DDGS that has a low digestibility of AA is used, pig performance may be reduced. In addition, the diets in the present experiment were formulated based on SID AA, whereas the diets used in some of the experiments in which poor pig performance was observed were formulated based on concentrations of total AA. Crystalline Lys was also added as DDGS was included in the diets used in this experiment, and these diets, therefore, contained only slightly more CP than the control diet. In many of the experiments in which poor performance of pigs fed DDGS-containing diets was reported, diets containing DDGS also contained much more CP than the control diet. In such diets, it may not be possible to determine if the poor performance is a result of the inclusion of DDGS in the diet or of the excess CP in the diets, because extra CP requires more energy for deamination of AA.

Values for ADG, ADFI, and final BW in the grower phase were lower for pigs fed HP-DDG compared with pigs fed conventional DDGS. Hastad et al. (2005) reported that decreased feed palatability amplifies with greater concentrations of DDGS in the diet. Therefore, the high inclusion levels (20 and 40%) of HP-DDG may have negatively affected ADFI in the grower phase.

Pigs fed corn germ diets had performance that was not different from pigs fed the control or DDGS diets. This observation demonstrates that corn germ is an excellent feed ingredient for pigs and that corn germ can be included in diets up to at least 10% without negatively affecting pig performance, provided that diets are formulated based on concentrations of digestible AA.

Carcass Composition

The carcass composition of pigs did not differ between pigs fed the control diets and pigs fed the DDGS or corn germ-containing diets. A decrease in dressing percentage as a result of dietary DDGS has been observed in some previous experiments (Cook et al., 2005; Whitney et al., 2006; Hinson et al., 2007), but in the current experiment, dressing percentage was not affected by the concentration of DDGS in the diet. The reason for this observation is unknown, but it may be related to the quality of DDGS that was used. The reason for the reduced LM area and LM depth in pigs fed diets containing HP-DDG is most likely that pigs fed these diets were smaller than the control pigs at slaughter.

Muscle and Fat Quality

The linear decrease in LM b* values for pigs fed diets containing DDGS or HP-DDG indicate that muscle color became more blue as these ingredients were included in the diets. To our knowledge, there are no other reports on LM b* values for pigs fed DDGS or HP-DDG, but the increased blueness in LM from pigs fed diets containing DDGS or HP-DDG could be a result of the numerical increase in LM pH that was observed for pigs fed these diets.

The decrease in belly firmness and adjusted belly firmness as the concentration of DDGS increased in the diet is in agreement with data from Whitney et al. (2006). However, no difference in belly thickness and iodine value was observed in this experiment. This is in contrast to Whitney et al. (2006), who reported a decrease in belly thickness and an increase in iodine value as the concentration of DDGS increased. However, Whitney et al. (2006) only decreased the inclusion of soybean oil by approximately 0.5% for each 10% increase in DDGS in the diets. In the present experiment, 1% soybean oil was removed from the formula for each 10% DDGS in the diet, and the concentration of fat in the DDGS-containing diets was slightly lower than in the control diet. This may explain why no increase in the iodine value was observed for pigs fed the DDGS-containing diets. The iodine value of bellies increased as the concentration of HP-DDG increased in the diet, which was expected because belly firmness and adjusted belly firmness had a tendency to decrease as the concentration of HP-DDG increased.

For pigs fed diets containing corn germ, the belly iodine value decreased at the 10% inclusion level but not at the 5% inclusion level. One possible explanation for this observation is that 2, 1, and 0% soybean oil was added to the control, 5% corn germ, and 10% corn germ diets, respectively. Soybean oil was added to the diets to ensure that all diets were formulated to contain the same amount of total fat. Therefore, the total fat in the diets did not increase when corn germ was included in the diets. However, fat in corn germ has a relatively low digestibility (Kil et al., 2007). This results in less fat being absorbed in pigs fed diets containing corn germ than in pigs fed control diets or DDGS-containing diets even if the concentration of fat in the diet is similar among these treatments. Pigs fed the corn germ diets may, therefore, have absorbed less of the unsaturated dietary fat, which in turn explains the reduction in iodine values for these pigs.

Palatability

The palatability of pork from pigs fed diets containing DDGS, HP-DDG, and corn germ has not been previously reported. Tenderness of bacon seemed to decrease with increasing levels of DDGS in diets, which may be a result of the tendency for reduced distortion of bacon from pigs fed DDGS-containing diets. Overall, the palatability of bacon and pork chops was not negatively affected by dietary treatments, which indicates that consumers would not be able to determine the difference among samples of pork obtained from pigs fed a corn-soybean meal-based diet or diets containing DDGS, HP-DDG, or corn germ.

In conclusion, including 20% DDGS in diets fed to growing-finishing pigs has no negative effects on growth performance, carcass composition, muscle quality, or pork palatability when diets are formulated based on SID AA and ATTD P. Belly firmness is negatively affected if 20% DDGS is included in the diet. The dietary inclusion of HP-DDG does not affect final pig performance, but belly firmness and iodine values are negatively affected by the addition of HP-DDG in the diet. Inclusion of up to 10% corn germ in diets fed to growing-finishing pigs has no detrimental effects on growth performance, carcass quality, or pork palatability, but the iodine value of belly fat is reduced if corn germ is included in the diet.

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