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Up to 30% corn germ may be included in diets fed to growing–finishing pigs without affecting pig growth performance, carcass composition, or pork fat quality

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Up to 30% corn germ may be included in diets fed to growing–finishing pigs without affecting pig growth performance, carcass composition, or pork fat quality[1]

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ABSTRACT: A total of 280 pigs (initial BW: 42.5 ± 4.6 kg) were used to determine effects of adding corn germ (15.6% CP; 16.6% acid hydrolyzed ether extract; 21.7% NDF) to diets fed to growing–finishing pigs. Pigs were randomly allotted to 1 of 8 dietary treatments in a 2 × 4 factorial arrangement of treatments with 2 levels of distillers dried grains with solubles (DDGS; 0 or 30%) and 4 levels of corn germ (0, 10, 20, or 30%). Each diet was fed to 10 pens with either 3 or 4 pigs per pen. Pigs were fed phase 1, 2, and 3 diets for 28, 28, and 27 d, respectively. At the conclusion of the experiment, 1 pig in each pen that had a BW that was closest to the average BW for the pen was harvested. For the overall experimental period, regardless of the level of DDGS, there was no effect of corn germ on pig growth performance, but inclusion of 30% DDGS in the diet reduced ($P < 0.001$) ADG, ADFI, and final BW. There were no effects of corn germ on carcass composition, muscle quality, or fat quality, but LM marbling and firmness were reduced ($P < 0.05$) by inclusion of DDGS in the diet. The L* value of LM decreased (linear and quadratic; $P < 0.05$) as corn germ was included in diets containing no DDGS, but that was not the case when corn germ was added to diets containing 30% DDGS (corn germ × DDGS; $P < 0.01$). Inclusion of DDGS in the diet reduced ($P < 0.001$) the L* value for backfat, but there were no effects of corn germ on backfat color measures. Inclusion of corn germ in diets containing no DDGS increased belly length (quadratic; $P < 0.05$), but that was not observed if corn germ was added to diets containing 30% DDGS. There was also a decrease in belly flop distance as corn germ was added to diets containing no DDGS (linear; $P < 0.001$), but no effects of corn germ were observed in diets containing 30% DDGS. However, inclusion of DDGS in the diet reduced ($P < 0.001$) the belly flop distance. In conclusion, addition of up to 30% corn germ in diets containing 0 or 30% DDGS did not negatively affect pig growth performance, carcass composition, or muscle quality, but belly firmness was reduced.

Key words: corn germ, distillers dried grains with solubles, fat quality, growth performance, pigs

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INTRODUCTION

Corn germ is produced by fractionation of corn into germ and endosperm, and the endosperm may then be used in the biofuels industry to produce ethanol whereas the corn germ may be used in diets fed to pigs (Rausch and Belyea, 2006). Digestibility of energy, P, AA, and CP in corn germ fed to growing–finishing pigs has been reported (Widmer et al., 2007), and growth performance of growing–finishing pigs was not negatively affected by diets containing up to 10% corn germ (Widmer et al., 2008). Up to 30% distillers dried grains with solubles (**DDGS**) may also be included in diets fed to growing–finishing pigs if a sufficient quantity of digestible Lys included in the diets (Stein and Shurson, 2009). However, belly fat firmness is reduced in pigs fed DDGS because fatty acid composition of the adipose tissues is altered by the high concentration of unsaturated fatty acids in DDGS (Whitney et al., 2006; Benz et al., 2010; Xu et al., 2010b).

Recently it has been reported that there are no negative effects on pig growth performance and fat quality of adding 15% corn germ to a diet containing 30% DDGS (Lee et al., 2011). It is possible that greater inclusion rates of corn germ can be used in diets fed to growing–finishing pigs, but research to test this hypothesis has not been reported. It is also not known if the presence of DDGS influences the responses to inclusion of corn germ in the diet. Therefore, an experiment was conducted to test the

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hypothesis that up to 30% of corn germ may be included in diets fed to growing–finishing pigs regardless of the level of DDGS in the diet without negatively affecting pig growth performance and pork fat quality. The objective of this experiment, therefore, was to determine the optimal inclusion rate of corn germ in growing–finishing pig diets containing 0 or 30% DDGS.

MATERIALS AND METHODS

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

Animals, Housing, Experimental Design, and Diets

A total of 280 gilts and barrows (G-perfomer boars × F-25 females; Genetiporc, Alexandria, MN) with an initial BW of 41.1 ± 4.2 kg were used. Pigs were housed in pens equipped with a feeder, a nipple drinker, and partly slatted concrete floors in an environmentally controlled building. Ad libitum access to feed and water was allowed throughout the experiment. Pigs were randomly allotted to 1 of 8 dietary treatments in a 2 × 4 factorial arrangement of treatments with 2 levels of DDGS (0 or 30%) and 4 levels of corn germ (0, 10, 20, or 30%). There were 10 replicate pens per diet, 5 replicates with 4 pigs per pen and 5 replicates with 3 pigs per pen, and there were an equal number of gilts and barrows on each treatment. Corn, soybean meal, DDGS, and corn germ were the main ingredients in the diets (Table 1). A 3-phase feeding program was used and grower diets (Table 2), early finisher diets (Table 3), and late finisher diets (Table 4) were provided for 28, 28, and 27 d, respectively. All diets within each phase were formulated to contain the same quantities of Ca, digestible P, and standardized ileal digestible indispensable AA, and estimates for nutrient requirements (NRC, 1998) were met or exceeded in all diets. In formulating the diets, it was assumed that the concentration of ME in DDGS and in corn germ was similar to that in corn (Widmer et al., 2007; Stein and Shurson, 2009).

Feeding and Growth Performance

Individual pig BW was recorded at the initiation of the experiment and at the conclusion of each of the 3 phases. Daily allotments of feed were recorded as well and the weight of feed left in the feeders was recorded at the conclusion of each of the 3 phases. At the conclusion of the experiment, data for ADG, ADFI, and G:F were summarized and calculated for each pen and diet. One pig from each pen was transported to the Meat Science Laboratory at the University of Illinois on the last day of the experiment. Before selecting the pig, 5 pens per treatment were randomly chosen to deliver gilts to the Meat Science Laboratory and barrows were selected from the other 5 pens. Within each pen, the pig of the determined gender that had a BW closest to the average for the pen was selected. Pigs were harvested after an overnight fast, but free access to water was allowed during this time.

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

Item	Corn	Soybean meal	DDGS	Corn germ
GE, kcal/kg	3,926	4,203	4,724	4,585
DM, %	86.03	88.28	87.33	87.61
Ash, %	1.25	6.82	5.06	6.25
CP, %	8.35	48.29	26.47	15.60
AEE,[1] %	3.68	2.13	11.11	16.64
ADF, %	2.23	4.81	7.68	5.55
NDF, %	8.18	9.74	27.58	21.72
Ca, %	0.01	0.46	0.06	0.06
P, %	0.23	0.67	0.91	1.34
Indispensable AA, %				
Arg	0.38	3.56	1.19	1.10
His	0.22	1.30	0.73	0.45
Ile	0.26	2.23	0.99	0.47
Leu	0.87	3.80	2.78	1.15
Lys	0.26	3.07	0.92	0.81
Met	0.16	0.66	0.52	0.24
Phe	0.35	2.48	1.23	0.60
Thr	0.27	1.87	0.99	0.54
Trp	0.06	0.70	0.19	0.11
Val	0.35	2.37	1.28	0.74
Dispensable AA, %				
Ala	0.54	2.10	1.71	0.92
Asp	0.48	5.34	1.60	1.16
Cys	0.17	0.65	0.52	0.27
Glu	1.32	8.62	3.40	2.00
Gly	0.30	2.06	1.00	0.75
Pro	0.63	2.29	1.92	0.99
Ser	0.34	2.10	1.03	0.56
Tyr	0.24	1.81	1.00	0.44

[1]AEE = acid hydrolyzed ether extract.

Slaughter and Carcass Evaluation

Before slaughter, the live BW was recorded for each pig. After electrical stunning, pigs were exsanguinated and scalded. Each carcass was de-haired and eviscerated, and HCW was recorded. Carcasses were stored at 4°C for 24 h. A pH meter (pH-STAR; SFK Technologies Inc., Cedar Rapids, IA) was used to determine the pH of the LM at the 10th rib of each pig 24 h postmortem. The LM from each carcass was collected and sampled from the edge of the LM to the outer edge of and perpendicular to the skin at the 10th rib and used to determine the fat depth at three-fourths distance. The LM was traced

Table 2. Composition of diets for growing pigs containing graded levels of corn germ and either 0 or 30% distillers dried grains with solubles (DDGS; as-fed basis)[1]

	Diet							
	0% DDGS				30% DDGS			
Item Corn germ, %:	0	10	20	30	0	10	20	30
Ingredient, %								
Ground corn	70.55	61.50	52.46	43.42	50.65	41.55	32.32	22.69
Soybean meal, 48% CP	27.00	26.10	25.20	24.30	17.10	16.10	15.20	14.60
DDGS	–	–	–	–	30.00	30.00	30.00	30.00
Corn germ	–	10.00	20.00	30.00	–	10.00	20.00	30.00
Ground limestone	0.75	0.86	0.97	1.08	1.07	1.24	1.36	1.58
Dicalcium phosphate	0.76	0.58	0.40	0.22	0.08	–	–	–
L-Lys HCl	0.15	0.15	0.15	0.15	0.37	0.37	0.37	0.37
DL-Met	0.04	0.05	0.05	0.05	–	–	–	–
L-Thr	0.05	0.06	0.07	0.08	0.03	0.04	0.05	0.06
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Energy and nutrients[3]								
GE, kcal/kg	3,883	3,957	4,005	4,157	4,148	4,215	4,360	4,411
DM, %	88.73	88.79	89.24	89.64	89.39	89.70	89.87	90.39
Ash, %	4.08	4.38	4.99	5.06	4.76	5.60	5.56	5.93
CP, %	19.97	18.71	19.13	20.25	20.78	21.60	21.95	21.48
AEE,[4] %	3.38	4.63	6.15	7.56	5.80	7.34	8.22	10.03
ADF, %	3.02	3.49	3.62	4.34	4.10	4.72	4.86	5.39
NDF, %	9.01	11.96	10.94	13.94	14.90	21.52	16.26	17.16
Ca, %	0.52	0.57	0.60	0.46	0.55	0.59	0.61	0.59
P, %	0.49	0.57	0.66	0.77	0.55	0.65	0.74	0.88
Indispensable AA, %								
Arg	1.19	1.29	1.19	1.28	1.13	1.26	1.25	1.33
His	0.50	0.53	0.49	0.52	0.54	0.60	0.59	0.60
Ile	0.75	0.74	0.71	0.72	0.75	0.81	0.80	0.81
Leu	1.56	1.63	1.45	1.51	1.84	2.03	1.99	1.93
Lys	1.10	1.18	1.09	1.15	1.18	1.30	1.24	1.41
Met	0.32	0.35	0.32	0.31	0.33	0.37	0.36	0.36
Phe	0.91	0.95	0.86	0.89	0.95	1.05	1.02	1.02
Thr	0.71	0.79	0.70	0.76	0.76	0.85	0.84	0.88
Trp	0.20	0.23	0.21	0.22	0.21	0.21	0.21	0.21
Val	0.86	0.86	0.83	0.87	0.90	1.00	1.00	1.03

[1]All diets were formulated to contain between 3.3 and 3.4 Mcal ME per kilogram, a minimum of 0.55% Ca and 0.23% digestible P, and the following quantities of standardized ileal digestible AA per kilogram: His, 0.32%; Ile, 0.56%; Lys, 1.0%; Met, 0.31%; Thr, 0.65%; Trp, 0.18%; and Val, 0.68%.

[2]The vitamin micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

[3]All values for energy and nutrients were analyzed.

[4]AEE = acid hydrolyzed ether extract.

(Super PLANIX α Polar Planimeter; Tamaya Technics Inc., Tokyo, Japan). An average of 2 tracings per LM was determined to calculate the LM area (Boler et al., 2011). On a scale from 1 to 6 (1 = pale pinkish gray to white and 6 = dark purplish red), subjective LM color scores were determined (NPPC, 1991). On a scale from 1 to 10 (1 = devoid and 10 = abundant), LM marbling scores were also determined (NPPC, 1999). Subjective LM firmness scores were determined using a scale from 1 to 5 (1 = very soft and watery and 5 = very firm and dry; NPPC, 1991). A colorimeter was used to measure objective color values (L*, a*, and b*; where L* = lightness, a* = redness, and b* = yellowness) of the loin muscle and the second fat layer (Minolta Chroma Meter, CR-300; Minolta Camera Co., Osaka, Japan). The loin muscle from the left side of each carcass was removed and a 2.5-cm chop from the LM was collected at the 10th rib. The loin chop was suspended for 24 h from a steel rod using a fish hook after being placed in a bag (Whirl-pak; Nasco, Fort Atkinson, WI). The initial weights of

Table 3. Composition of diets for early finishing pigs containing graded levels of corn germ and either 0 or 30% distillers dried grains with solubles (DDGS; as-fed basis)[1]

	Diet							
	0% DDGS				30% DDGS			
Item Corn germ, %:	0	10	20	30	0	10	20	30
Ingredient								
Ground corn	77.38	68.34	59.30	50.23	55.49	46.17	36.87	27.62
Soybean meal, 48% CP	20.50	19.60	18.70	17.80	12.50	11.60	10.70	9.80
DDGS	–	–	–	–	30.00	30.00	30.00	30.00
Corn germ	–	10.00	20.00	30.00	–	10.00	20.00	30.00
Ground limestone	0.67	0.78	0.89	1.05	1.00	1.22	1.42	1.57
Dicalcium phosphate	0.56	0.38	0.20	–	–	–	–	–
L-Lys HCl	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30
DL-Met	0.01	0.01	0.01	0.01	–	–	–	–
L-Thr	0.03	0.04	0.05	0.06	–	–	–	–
L-Trp	–	–	–	–	0.01	0.01	0.01	0.01
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Energy and nutrients[3]								
GE, kcal/kg	3,838	3,939	4,045	4,137	4,182	4,227	4,286	4,297
DM, %	87.61	87.66	88.73	88.74	88.44	88.80	89.22	89.43
Ash, %	3.85	3.91	4.69	4.93	4.43	4.88	5.60	6.25
CP, %	15.95	15.93	16.92	17.70	18.81	18.58	19.65	19.67
AEE,[4] %	2.97	4.74	6.11	7.27	6.51	7.62	8.65	10.51
ADF, %	2.89	3.34	3.83	4.41	4.36	4.80	5.22	5.45
NDF, %	9.18	10.67	12.05	12.51	13.75	17.32	17.44	19.31
Ca, %	0.49	0.44	0.51	0.47	0.54	0.52	0.65	0.69
P, %	0.45	0.52	0.59	0.66	0.50	0.61	0.72	0.84
Indispensable AA, %								
Arg	0.87	1.05	1.02	1.11	0.98	1.05	1.06	1.11
His	0.38	0.46	0.44	0.47	0.50	0.53	0.52	0.54
Ile	0.55	0.66	0.62	0.66	0.71	0.73	0.70	0.71
Leu	1.22	1.43	1.33	1.38	1.72	1.79	1.75	1.72
Lys	0.81	0.97	0.95	1.02	1.03	1.06	1.06	1.10
Met	0.23	0.27	0.25	0.26	0.32	0.34	0.33	0.34
Phe	0.68	0.80	0.75	0.79	0.86	0.89	0.87	0.87
Thr	0.54	0.63	0.62	0.65	0.65	0.70	0.70	0.68
Trp	0.19	0.19	0.19	0.19	0.18	0.19	0.19	0.18
Val	0.63	0.78	0.74	0.81	0.88	0.91	0.90	0.94

[1]All diets were formulated to contain between 3.3 and 3.4 Mcal ME per kilogram, a minimum of 0.46% Ca and 0.19% digestible P, and the following quantities of standardized ileal digestible AA per kilogram: His, 0.26%; Ile, 0.45%; Lys, 0.83%; Met, 0.25%; Thr, 0.54%; Trp, 0.15%; and Val, 0.56%.

[2]The vitamin micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

[3]All values for energy and nutrients were analyzed.

[4]AEE = acid hydrolyzed ether extract.

the loin chop were recorded and compared with the final weights to determine drip loss (Boler et al., 2011). The belly was removed from the left side of each carcass and laid flat on a stainless steel table and chilled for 24 h at 2ºC. The belly length was determined from the cranial to the caudal end. The distance from the dorsal to the ventral edge was measured to determine belly width. Each belly was then draped over a suspended, stainless steel rod with the skin side down to perform a flop test. At a standardized point, which was 10 cm down from the stainless steel rod, the distance from skin surface to skin surface was measured (Leick et al., 2010).

Chemical Analysis

All diets and the main ingredients (corn, soybean meal, DDGS, and corn germ) were analyzed for GE using bomb calorimetry (Model 6300; Parr Instruments,

Table 4. Composition of diets for late finishing pigs containing graded levels of corn germ and either 0 or 30% distillers dried grains with solubles (DDGS; as-fed basis)[1]

	Diet							
	0% DDGS				30% DDGS			
Item Corn germ, %:	0	10	20	30	0	10	20	30
Ingredient								
Ground corn	82.08	73.00	63.95	54.90	60.05	50.70	41.45	32.30
Soybean meal, 48% CP	16.00	15.10	14.20	13.30	8.00	7.10	6.20	5.30
DDGS	–	–	–	–	30.00	30.00	30.00	30.00
Corn germ	–	10.00	20.00	30.00	–	10.00	20.00	30.00
Ground limestone	0.60	0.72	0.80	0.89	0.93	1.18	1.33	1.38
Dicalcium phosphate	0.45	0.30	0.15	–	–	–	–	–
L-Lys HCl	0.15	0.15	0.15	0.15	0.30	0.30	0.30	0.30
DL-Met	–	–	0.01	0.01	–	–	–	–
L-Thr	0.02	0.03	0.04	0.05	–	–	–	–
L-Trp	–	–	–	–	0.02	0.02	0.02	0.02
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin mineral premix[2]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Energy and nutrients[3]								
GE, kcal/kg	3,850	3,962	4,052	4,128	4,182	4,274	4,354	4,408
DM, %	88.04	88.11	88.57	89.12	88.46	89.19	89.22	88.72
Ash, %	3.60	3.79	4.27	4.75	4.13	4.86	4.91	5.82
CP, %	15.24	15.44	15.56	16.27	17.26	17.54	17.98	18.67
AEE,[4] %	2.21	4.34	5.02	6.42	5.79	6.31	7.85	8.37
ADF, %	2.73	3.16	3.37	3.49	4.07	4.41	4.71	4.99
NDF, %	9.79	10.56	10.45	12.64	14.66	16.36	16.10	15.23
Ca, %	0.42	0.48	0.41	0.46	0.47	0.56	0.45	0.59
P, %	0.39	0.48	0.56	0.66	0.49	0.60	0.70	0.84
Indispensable AA, %								
Arg	0.90	0.91	0.98	1.00	0.86	0.91	0.92	1.01
His	0.41	0.40	0.42	0.43	0.44	0.47	0.46	0.50
Ile	0.61	0.56	0.58	0.59	0.57	0.60	0.58	0.64
Leu	1.34	1.27	1.31	1.31	1.59	1.65	1.61	1.68
Lys	0.86	0.87	0.89	0.95	0.90	0.92	0.90	1.00
Met	0.24	0.23	0.24	0.25	0.30	0.31	0.31	0.32
Phe	0.72	0.70	0.72	0.70	0.76	0.79	0.77	0.81
Thr	0.55	0.56	0.60	0.61	0.62	0.64	0.64	0.66
Trp	0.16	0.16	0.16	0.16	0.18	0.18	0.19	0.18
Val	0.71	0.67	0.72	0.73	0.71	0.78	0.76	0.85

[1]All diets were formulated to contain between 3.3 and 3.4 Mcal ME per kilogram, a minimum of 0.40% Ca and 0.17% digestible P, and the following quantities of standardized ileal digestible AA per kilogram: His, 0.23%; Ile, 0.40%; Lys, 0.72%; Met, 0.22%; Thr, 0.47%; Trp, 0.13%; and Val, 0.49%.

[2]The vitamin micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu, 10 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 1.26 mg as potassium iodate; Mn, 60 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; and Zn, 100 mg as zinc oxide.

[3]All values for energy and nutrients were analyzed.

[4]AEE = acid hydrolyzed ether extract.

Moline, IL). Benzoic acid was used as a calibration standard. Ingredients and diets were also analyzed for DM by oven drying at 135°C for 2 h (Method 930.15; AOAC Int., 2007) and dry ash (Method 942.05; AOAC Int., 2007). A combustion procedure (Method 990.03; AOAC Int., 2007) on an apparatus (Elemental Rapid N-cube Protein/Nitrogen Apparatus; Elementar Americas Inc., Mt. Laurel, NJ) was used to determine CP concentration in diets and ingredients. Aspartic acid was used as the standard for calibration, and CP was calculated as N × 6.25. Acid hydrolyzed ether extract analysis was performed to determine the concentration of fat in the ingredients and diets (Method 2003.06; AOAC Int., 2007) with an automated analyzer (Soxtec 2050; FOSS North America, Eden Prairie, MN). An AA analyzer (Model number L8800; Hitachi High Technologies America, Inc., Pleasanton, CA) was used to analyze the concentration of AA in all diets and ingredients using

Table 5. Growth performance of pigs fed diets containing graded levels of corn germ (CG) and either 0 or 30% distillers dried grains with solubles (DDGS)[1]

	Diet									*P*-value							
	0% DDGS				30% DDGS							DDGS	0% DDGS		30% DDGS		
Item CG, %:	0	10	20	30	0	10	20	30	SEM	DDGS	CG	× CG	Linear[2]	Q[2]	Linear	Q	
Growing period																	
Initial BW, kg	40.97	40.99	40.80	41.21	41.42	40.86	40.93	41.11	0.75	0.87	0.96	0.98	0.88	0.80	0.80	0.63	
ADG, kg	0.97	1.00	1.04	1.02	0.91	0.93	0.92	0.91	0.02	<0.001	0.46	0.47	0.07	0.31	0.95	0.70	
ADFI, kg	2.07	2.22	2.18	2.05	1.87	2.00	1.89	1.95	0.10	<0.01	0.49	0.81	0.82	0.15	0.75	0.67	
G:F, kg/kg	0.48	0.46	0.48	0.51	0.51	0.47	0.49	0.47	0.02	0.91	0.65	0.57	0.37	0.33	0.38	0.78	
Final BW, kg	68.26	68.97	69.90	69.76	66.94	66.79	66.57	66.67	0.97	<0.001	0.90	0.72	0.21	0.66	0.81	0.89	
Early finishing period																	
ADG, kg	1.03	1.00	1.04	0.97	0.96	0.95	0.96	0.94	0.03	<0.01	0.42	0.75	0.24	0.48	0.85	0.95	
ADFI, kg	2.65	2.73	2.63	2.64	2.56	2.48	2.52	2.50	0.14	0.14	1.00	0.93	0.80	0.80	0.82	0.83	
G:F, kg/kg	0.39	0.38	0.41	0.38	0.38	0.39	0.39	0.39	0.02	0.90	0.95	0.89	0.84	0.80	0.81	0.85	
Final BW, kg	97.06	96.96	98.90	96.87	93.70	93.26	93.37	93.10	1.28	<0.001	0.81	0.83	0.81	0.45	0.77	0.95	
Late finishing period																	
ADG, kg	1.09	1.00	1.02	1.02	0.96	0.94	0.99	0.97	0.03	<0.001	0.18	0.30	0.14	0.06	0.65	0.98	
ADFI, kg	3.39	3.39	3.32	3.33	3.09	3.14	3.19	3.10	0.08	<0.001	0.94	0.76	0.51	0.94	0.82	0.38	
G:F, kg/kg	0.32	0.30	0.31	0.31	0.31	0.30	0.31	0.31	0.01	0.91	0.22	0.91	0.59	0.14	0.76	0.37	
Final BW, kg	126.43	123.88	126.36	124.51	119.74	118.70	120.10	119.19	1.52	<0.001	0.51	0.95	0.63	0.82	0.97	0.97	
Entire period																	
ADG, kg	1.03	1.00	1.03	1.00	0.94	0.94	0.95	0.94	0.02	<0.001	0.42	0.86	0.54	0.91	0.92	0.83	
ADFI, kg	2.82	2.90	2.83	2.79	2.62	2.65	2.65	2.62	0.06	<0.001	0.66	0.89	0.53	0.32	1.00	0.62	
G:F, kg/kg	0.36	0.35	0.36	0.37	0.36	0.35	0.36	0.36	0.01	0.71	0.22	0.75	0.43	0.16	0.99	0.73	

[1]Data are means of 10 observations per treatment.

[2]Linear = linear effect of corn germ; Q = quadratic effect of corn germ.

ninhydrin for postcolumn derivatization and norleucine as the internal standard. All samples were hydrolyzed with 6 *M* HCl for 24 h at 110°C [Method 982.30 E(a); AOAC Int., 2007] before analysis. Methionine and Cys were determined as Met sulfone and cysteic acid after an overnight cold performic acid oxidation before acid hydrolysis [Method 982.30 E(b); AOAC Int., 2007]. The concentration of Trp was determined after NaOH hydrolysis for 22 h at 110°C [Method 982.30 E(c); AOAC Int., 2007]. Analysis for ADF [Method 973.18; AOAC Int., 2007] and NDF (Holst, 1973) was performed in all diets and ingredients and Ca and P were analyzed by using coupled plasma spectroscopy (Method 985.01; AOAC Int., 2007).

Statistical Analysis

Data were analyzed using PROC MIXED (SAS Inst. Inc., Cary, NC) as a 2 × 4 factorial arrangement of treatments with DDGS and corn germ as the 2 factors. The pen was the experimental unit for all analyses. The model included corn germ, DDGS, and the interaction between DDGS and corn germ as fixed effects and replicate as the random effect. Least squares means were calculated for each independent variable. Linear and quadratic effects of inclusion of corn germ in diets without or with DDGS were determined using orthogonal polynomial contrasts. Significance was determined at $P \leq 0.05$ for all statistical analyses and tendencies were determined at $0.05 > P \leq 0.10$.

RESULTS

Growth Performance

Initial BW of pigs did not differ among the 8 dietary treatments (Table 5). There were no linear or quadratic effects of including graded levels of corn germ in diets without or with DDGS on ADG, ADFI, G:F, or final BW during the growing, early finishing, or late finishing phases or during the entire experimental period. However, there was a tendency for ADG to increase in the growing period with increasing levels of corn germ if no DDGS was included in the diet (linear; $P = 0.07$). On the other hand, there was a trend for ADG to decrease as corn germ was added to diets that contained no DDGS in the late finishing period (quadratic; $P = 0.06$).

Average daily gain and ADFI for pigs fed diets containing no DDGS were greater ($P < 0.01$) than for pigs fed diets containing 30% DDGS during the growing, the late finishing, and the entire experimental period, and ADG for pigs fed diets that contained no DDGS was also greater ($P < 0.01$) than for pigs fed diets that contained 30% DDGS during the early finishing period. Average G:F values, how-

Table 6. Carcass composition, muscle quality, and backfat quality of pigs fed diets containing graded levels of corn germ (CG) and either 0 or 30% distillers dried grains with solubles (DDGS)[1]

	Diet									*P*-value						
	0% DDGS				30% DDGS							DDGS	0% DDGS		30% DDGS	
Item CG, %:	0	10	20	30	0	10	20	30	SEM	DDGS	CG	× CG	Linear[2]	Q[2]	Linear	Q
BW, kg	121.6	118.4	122.5	118.25	116.4	114.6	114.1	115.6	2.4	<0.01	0.69	0.65	0.58	0.81	0.78	0.49
Carcass composition																
HCW, kg	96.1	93.7	96.8	93.4	92.0	91.0	89.8	91.4	1.9	<0.01	0.78	0.56	0.55	0.78	0.74	0.49
Dressing, %	79.1	79.2	79.0	78.9	79.0	79.4	78.7	79.1	0.3	0.90	0.63	0.76	0.69	0.85	0.78	0.96
Backfat, cm	2.02	1.86	2.06	2.07	1.64	2.04	1.77	1.68	0.15	0.05	0.88	0.19	0.61	0.56	0.81	0.11
LM area, cm^2	56.1	53.2	53.0	54.9	53.1	53.2	51.1	53.8	1.6	0.18	0.34	0.81	0.58	0.13	1.00	0.40
FFL,[3] %	54.7	55.1	53.8	54.8	56.1	54.4	55.1	56.1	0.9	0.16	0.72	0.58	0.63	0.87	0.83	0.16
Muscle quality																
Subjective color[4]	2.1	2.3	2.4	2.2	2.5	2.1	2.2	2.2	0.1	1.00	0.79	0.11	0.52	0.15	0.20	0.15
Marbling[5]	1.3	1.3	1.4	1.4	1.1	1.0	1.1	1.2	0.2	0.02	0.78	0.97	0.56	1.00	0.56	0.51
Firmness[6]	2.8	2.9	3.1	3.0	2.5	2.7	2.4	2.1	0.2	<0.01	0.61	0.27	0.38	0.62	0.10	0.22
24-h pH, LM	5.5	5.6	5.6	5.6	5.7	5.6	5.6	5.6	0.0	0.31	0.84	0.06	0.12	0.27	0.30	0.15
48-h drip loss, %	5.9	3.8	4.0	3.6	4.6	5.0	4.5	5.6	0.9	0.40	0.71	0.32	0.11	0.35	0.52	0.68
LM color, L*[7]	51.3	47.0	47.6	47.9	46.6	48.4	48.3	47.8	0.9	0.29	0.50	<0.01	0.02	0.01	0.38	0.24
LM color, a*[7]	7.9	8.2	7.9	7.2	8.1	7.9	8.1	8.0	0.6	0.60	0.81	0.79	0.29	0.37	0.97	0.95
LM color, b*[7]	3.7	2.7	2.6	2.3	3.0	3.2	3.2	2.9	0.5	0.53	0.53	0.52	0.06	0.52	0.89	0.61
Backfat color																
Fat color, L*	75.0	73.9	74.4	73.7	73.1	73.2	72.1	72.9	0.4	<0.001	0.16	0.12	0.06	0.54	0.35	0.36
Fat color, a*	4.0	4.3	3.5	3.8	4.2	3.5	4.2	3.8	0.3	0.90	0.84	0.18	0.37	0.91	0.79	0.65
Fat color, b*	4.0	3.9	3.8	3.8	4.3	4.2	3.9	4.0	0.3	0.19	0.63	0.97	0.56	0.97	0.28	0.67

[1]Data are means of 10 observations per treatment.
[2]Linear = linear effect of corn germ; Q = quadratic effect of corn germ.
[3]FFL = fat free lean (%) as calculated using NPPC (1999) equation.
[4]NPPC (1991) color scale (1 to 6): 1 = pale pinkish gray to white and 6 = dark purplish red.
[5]NPPC (1999) marbling scale (1 to 10): 1 = devoid and 10 = abundant.
[6]NPPC (1991) firmness scale (1 to 5): 1 = very soft and 5 = very firm and dry.
[7]L* = lightness; a* = redness; b* = yellowness

ever, were not influenced by DDGS in the diet. The BW of pigs fed no DDGS was greater ($P < 0.001$) than for pigs fed diets containing 30% DDGS at the end of each phase.

Carcass Composition and Muscle and Backfat Quality

There were no effects on BW, HCW, dressing percentage, backfat, LM area, or fat free lean percentage of including corn germ in diets (Table 6). However, BW and HCW were greater ($P < 0.01$) for pigs fed no DDGS than for pigs fed 30% DDGS. Backfat was also greater ($P < 0.05$) for pigs fed diets without DDGS than for pigs fed diets with DDGS, but dressing percentage, LM area, and fat-free lean percentage were not affected by including DDGS in the diets. Interactions between DDGS and corn germ were not significant for any of the carcass composition measures assessed.

No linear or quadratic effects of including corn germ on LM subjective color, marbling, firmness, pH, drip loss, or LM a* value were observed regardless of the level of DDGS in the diets. However, the LM L* value decreased as corn germ was included in diets containing 0% DDGS (linear and quadratic; $P < 0.05$), but that was not observed as corn germ was included in diets containing 30% DDGS (corn germ × DDGS; $P < 0.01$). A trend for decreased LM b* values was also observed as corn germ was added to diets without DDGS (linear; $P = 0.06$). Pigs fed diets containing no DDGS had greater ($P < 0.05$) marbling than for pigs fed diets containing 30% DDGS, and LM firmness was greater ($P < 0.01$) for pigs fed diets containing 0% DDGS than pigs fed diets containing 30% DDGS. There was a tendency ($P = 0.06$) for an interaction between corn germ and DDGS in 24 h pH with values increasing as corn germ was added to diets without DDGS, but decreasing as corn germ was added to diets containing 30% DDGS.

There were no linear or quadratic effects of corn germ on backfat a* and b* values regardless of the level of DDGS in the diet. However, there was a tendency (linear; $P = 0.06$) for decreased backfat L* values as corn germ was added to diets containing no DDGS. Backfat L* value for pigs fed 0% DDGS also was greater ($P < 0.001$) than the backfat L* value for pigs fed diets con-

Table 7. Belly quality of pigs fed diets containing graded levels of corn germ (CG) and either 0 or 30% distillers dried grains with solubles (DDGS)[1]

	Diet									*P*-value							
	0% DDGS				30% DDGS								0% DDGS		30% DDGS	
Item CG, %:	0	10	20	30	0	10	20	30	SEM	DDGS	CG[2]	DDGS × CG	Linear[2]	Q[2]	Linear	Q
Belly length, cm	57.05	59.21	58.75	56.51	57.23	56.69	56.44	56.67	1.00	0.12	0.56	0.36	0.65	0.03	0.67	0.71
Belly width, cm	22.91	23.70	23.93	23.44	24.18	24.39	24.13	23.50	0.76	0.31	0.81	0.85	0.59	0.40	0.50	0.58
Belly wt, kg	5.10	5.36	5.51	5.16	5.11	5.22	4.92	4.88	0.19	0.06	0.51	0.44	0.71	0.11	0.24	0.70
Flop distance,[3] cm	17.37	14.28	11.66	9.98	8.10	9.45	7.37	6.22	1.53	<0.001	0.01	0.26	<0.001	0.64	0.26	0.42

[1]Data are means of 10 observations per treatment.

[2]Linear = linear effect of corn germ; Q = quadratic effect of corn germ.

[3]A flop test was performed by draping a centered belly lengthwise over a suspended, stainless steel rod with the skin side down. The distance from skin surface to skin surface was measured at a standardized point, 10 cm down from the stainless steel rod.

taining 30% DDGS.

Belly Quality Measurements

There were no linear or quadratic effects on belly length of including corn germ in diets containing 30% DDGS, but belly length increased (quadratic; $P < 0.05$) as corn germ was included in diets containing no DDGS (Table 7). However, belly width and belly weight were not affected by inclusion of corn germ to the diets regardless of the level of DDGS in the diets. In contrast, there was a decrease in belly flop distance with inclusion of corn germ in diets containing no DDGS (linear; $P < 0.001$) whereas belly flop distance was not affected by corn germ in diets containing 30% DDGS. There were no effects of DDGS on belly length or belly width, but there was a tendency ($P = 0.06$) for reduced belly weight in pigs fed diets containing 30% DDGS compared with pigs fed no DDGS. Belly flop distance also was reduced ($P < 0.001$) as DDGS was included in the diet.

DISCUSSION

Distillers dried grains with solubles used in this experiment contained slightly less CP but a greater concentration of Lys, than the average for DDGS (Stein and Shurson, 2009). The Lys:CP was 3.48%, which is above the average Lys:CP (3.21%) for DDGS that was calculated in a previous experiment (Stein et al., 2009) but in close agreement with results of another recent experiment (Kim et al., 2012). The Lys:CP in DDGS used in this experiment was greater than the Lys:CP in corn (3.11%), which is most likely because yeast is added to the corn during fermentation, which may result in synthesis of microbial protein that has a greater Lys:CP than corn (Han and Liu, 2010). These observations indicate that the DDGS used in this experiment was not heat damaged because heat damage will reduce the Lys:CP because of destruction of Lys in the Mailard reaction (Kim et al., 2012).

The crude fat level of 16.64% in the corn germ used in this experiment is close to reported values of 17.60 and 17.32% (Widmer et al., 2007, 2008), and the concentration of other nutrients in corn germ were also in agreement with previously reported values. If corn germ is defatted, corn germ meal is produced and the concentration of crude fat in corn germ meal is approximately 2% (Weber et al., 2009). Corn germ and corn germ meal, therefore, are different feed ingredients, and results obtained with one of these ingredients should not be extrapolated to the other without experimental verification.

The relatively high concentration of crude fat in DDGS and corn germ compared with corn and soybean meal results in diets containing greater concentrations of fat if DDGS or corn germ is used. However, the concentration of ADF and NDF in DDGS and corn germ is much greater than in corn, and the concentration of ME in DDGS and corn germ is, therefore, not greater than in corn (Widmer et al., 2007; Stein and Shurson, 2009). As a consequence, inclusion of DDGS and corn germ in diets based on corn and soybean meal only has minimal impact on diet ME values, which was also illustrated in this experiment. The fact that values for G:F were not influenced by the levels of corn germ or DDGS in the diets provides support to the hypothesis that ME values in DDGS and corn germ are similar to the ME in corn.

Growth Performance

Growth performance of growing–finishing pigs was not affected by inclusion of 10% corn germ to a corn–soybean meal-based diet (Widmer et al., 2008) or by addition of 15% corn germ to corn–soybean meal diets containing 30% DDGS (Lee et al., 2011). Results of this experiment are in agreement with the previous reports and indicate that, under these experimental conditions, up to 30% corn germ may be included in growing–finishing pig diets containing up to 30% DDGS without negatively affecting pig growth.

Inclusion of up to 30% DDGS in diets fed to growing–finishing pigs has been reported not to affect pig growth performance (Linneen et al., 2008; Drescher et al., 2009; Lammers et al., 2009; Xu et al., 2010b), and only minor negative effects on ADG but not on ADFI and G:F by including up to 45% DDGS in corn–soybean meal-based diets fed to growing–finishing pigs have been reported (Cromwell et al., 2011). On the other hand, reduced growth performance of growing–finishing pigs fed corn–soybean meal-based diets containing 30% DDGS has also been reported (Whitney et al., 2006; Xu et al., 2010a). It is not clear why growth performance is reduced by the inclusion of 30% DDGS in some experiments, but not in others. The fact that ADG, ADFI, and final BW, but not G:F were reduced in this experiment in pigs fed diets containing 30% DDGS indicates that the main reason for the reduced growth of pigs fed DDGS containing diets is reduced ADFI of these diets compared with pigs fed corn–soybean meal-based diets.

Carcass Composition and Quality

Carcass composition and carcass quality were not negatively affected by inclusion of up to 10% corn germ in a corn–soybean meal-based diet (Widmer et al., 2008) and there were very few effects on carcass composition and carcass quality of adding 15% corn germ to a diet containing 30% DDGS (Lee et al., 2011). Results of this experiment are in close agreement with those observations and also indicate that, under conditions similar to those used in this experiment, carcass composition and quality will not be affected by inclusion of up to 30% corn germ in the diets. The fact that very few interactions between corn germ and DDGS were observed indicates that effects of adding corn germ to the diets are independent of the level of DDGS in the diet. There are also very limited effects on carcass composition and carcass quality of including DDGS in diets fed to growing–finishing pigs (Whitney et al., 2006; Widmer et al., 2008; Xu et al., 2010a) and results of the present experiment are in agreement with these observations.

Belly Quality Measurements

A reduction in belly firmness of pigs fed diets containing DDGS has been reported (Benz et al., 2010; Xu et al., 2010a; Cromwell et al., 2011) and results of this experiment confirm these observations. However, the reduced belly firmness for pigs fed diets containing corn germ is not in agreement with Widmer et al. (2008) who reported that there were no effects of adding 10% corn germ to a corn–soybean meal-based diet on belly firmness. The reason for the differences between the 2 experiments may be that a greater inclusion rate of corn germ was used in this experiment than in the experiment by Widmer et al. (2008), which increased the total amount of corn oil in the diet compared with the level of corn oil in diets containing 10% corn germ. In addition, in the experiment by Widmer et al. (2008), 2% soybean oil was included in the corn–soybean meal diet, but not in the corn germ diet, in an attempt to maintain similar fat concentrations among diets. However, in the present experiment, no attempts were made to maintain constant fat concentrations among diets and fat levels, therefore, increased as corn germ was included in the diets, which most likely contributed to the reduced belly firmness in pigs fed diets containing corn germ. The present results, therefore, indicate that feeding increasing levels of corn oil from either DDGS or from corn germ will result in soft bellies of growing–finishing pigs.

The negative effects of DDGS on fat quality may be ameliorated by removal of DDGS from the diets during the final weeks before harvest (Gaines et al., 2007; Hill et al., 2008; Xu et al., 2010a). To our knowledge, no experiments have been reported in which effects of withdrawing corn germ from diets fed to finishing pigs was investigated, but it is possible that negative effects of corn germ on belly firmness may be reduced if the concentration of corn germ in the diets is reduced during the final 2 to 4 wk before harvest.

CONCLUSIONS

Inclusion of up to 30% corn germ in diets fed to growing–finishing pigs does not negatively impact pig growth performance, carcass composition, or carcass quality, and effects of using corn germ are independent of the level of DDGS in the diet. However, feeding corn germ to finishing pigs may result in reduced belly firmness of the pigs even if no DDGS is included in the diet. It is possible that reducing the inclusion rate of corn germ in the late finishing diets fed to pigs may ameliorate the negative effects of corn germ on belly quality, but this hypothesis has not been tested.

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