JOURNAL OF ANIMAL SCIENCE
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B. G. Kim, Y. Zhang and H. H. Stein

J ANIM SCI 2012, 90:272-281.
doi: 10.2527/jas.2010-3777 originally published online August 26, 2011

Sulfur concentration in diets containing corn, soybean meal, and distillers dried grains with solubles does not affect feed preference or growth performance of weanling or growing-finishing pigs[1]

B. G. Kim,*[2] Y. Zhang,† and H. H. Stein*[3]

*Department of Animal Sciences, University of Illinois, Urbana 61801; and †National Corn to Ethanol Research Center, Edwardsville, IL 62025

ABSTRACT: Four experiments were conducted to investigate the effects of distillers dried grains with solubles (DDGS) and dietary S on feed preference and performance of pigs. In a 10-d feed preference experiment (Exp. 1), 48 barrows (20.1 ± 2.2 kg of BW) were randomly allotted to 3 treatment groups, with 8 replicate pens per treatment and 2 pigs per pen. A control diet based on corn and soybean meal, a DDGS diet containing 20% DDGS, and a DDGS-sulfur (DDGS-S) diet were prepared. The DDGS-S diet was similar to the DDGS diet with the exception that 0.74% $CaSO_4$ was added to the diet. Two diets were provided in separate feeders in each pen: 1) the control diet and the DDGS diet, 2) the control diet and the DDGS-S diet, or 3) the DDGS diet and the DDGS-S diet. Preference for the DDGS diet and the DDGS-S diet vs. the control diet was 35.2 and 32.6%, respectively ($P < 0.05$), but there was no difference between the DDGS diet and the DDGS-S diet. In Exp. 2, a total of 90 barrows (10.3 ± 1.4 kg of BW) were allotted to 3 treatments, with 10 replicate pens and 3 pigs per pen, and were fed the diets used in Exp. 1 for 28 d, but only 1 diet was provided per pen. Pigs fed the control diet gained more BW (497 vs. 423 and 416 g/d; $P < 0.05$) and had greater G:F (0.540 vs. 0.471 and 0.455; $P < 0.05$) than pigs fed the DDGS or the DDGS-S diet, but no differences between the DDGS and the DDGS-S diets were observed. In a 10-d feed preference experiment (Exp. 3), 30 barrows (49.6 ± 2.3 kg of BW) were allotted to 3 treatment groups, with 10 replicates per group. The experimental procedures were the same as in Exp. 1, except that 30% DDGS was included in the DDGS and DDGS-S diets and 1.10% $CaSO_4$ was added to the DDGS-S diet. Feed preference for the DDGS and the DDGS-S diets, compared with the control diet, was 29.8 and 32.9%, respectively ($P < 0.01$), but there was no difference between the DDGS and the DDGS-S diets. In Exp. 4, a total of 120 barrows (34.2 ± 2.3 kg of BW) were fed grower diets for 42 d and finisher diets for 42 d. Diets were formulated as in Exp. 3. Pigs on the control diets gained more BW (1,021 vs. 912 and 907 g/d; $P < 0.05$) and had greater G:F (0.335 vs. 0.316 and 0.307; $P < 0.05$) than pigs fed the DDGS or DDGS-S diet, respectively, but no differences between pigs fed the DDGS and the DDGS-S diets were observed. In conclusion, dietary S concentration does not negatively affect feed preference, feed intake, or growth performance of weanling or growing-finishing pigs fed diets based on corn, soybean meal, and DDGS.

Key words: distillers dried grains with solubles, feed preference, growth performance, pig, sulfur

J. Anim. Sci. 2012. 90:272–281
doi:10.2527/jas.2010-3777

INTRODUCTION

Distillers dried grains with solubles (**DDGS**) may be used in diets fed to pigs (Stein and Shurson, 2009), and the digestibility of energy, P, and AA in corn DDGS fed to pigs has been reported (Fastinger and Mahan, 2006; Stein et al., 2006; Pedersen et al., 2007). In growth performance experiments, inclusion of 20 to 30% DDGS in diets fed to weanling or growing-finishing pigs has not affected pig growth performance in some experiments (Whitney and Shurson, 2004; Cook et al., 2005; Widmer et al., 2008). However, reduced feed intake of diets containing DDGS has been reported from other experiments (Whitney et al., 2006; Barbosa et al., 2008; Linneen et al., 2008). It has also been reported that if given a choice, pigs prefer to eat diets containing no

[1]This manuscript is based on research funded by the National Pork Board (Des Moines, IA) and the Nutritional Efficiency Consortium (Des Moines, IA).

[2]Present address: Department of Animal Science and Environment, Konkuk University, Seoul 143-701, South Korea.

[3]Corresponding author: hstein@illinois.edu

Received December 11, 2010.
Accepted August 19, 2011.

DDGS rather than diets containing DDGS (Hastad et al., 2005; Seabolt et al., 2010). It has, however, not been elucidated why feed intake is reduced under certain situations when DDGS is included in the diets.

It is possible that the reason for the reduced preference of pigs for diets containing DDGS is that some sources of DDGS contain relatively high concentrations of S. The concentration of S varies among sources of DDGS (Spiehs et al., 2002; Kerr et al., 2008). The tolerable concentration of dietary S in diets fed to cattle is suggested to be 0.4% of DM (NRC, 1996), but to our knowledge, the tolerance for S in diets fed to pigs has not been determined. The objective of the present experiments, therefore, was to test the hypothesis that greater concentrations of S in DDGS-containing diets may negatively affect the feed preference and growth performance of weanling and growing-finishing pigs.

MATERIALS AND METHODS

The protocol for each of 4 experiments was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. All experiments were conducted in environmentally controlled rooms at the University of Illinois at Urbana-Champaign. All pigs used in these experiments were Landrace (3/4) × Large White (1/4) cross-bred barrows (Genetiporc, Alexandria, MN).

Before the start of the animal experiments, corn DDGS samples from 35 ethanol plants in the United States were obtained and analyzed for S. It was observed that the concentration of S in corn DDGS varied from 0.30 to 0.90% (as-fed basis; Table 1). As a consequence, a source of DDGS that contained 0.30% S was procured and used in these experiments. The same batch of this source of DDGS was used in all 4 experiments.

Exp. 1: Feed Preference, Weanling Pigs

Three diets were formulated (Table 2). The control diet consisted of ground corn and dehulled soybean meal supplemented with minerals and vitamins to meet or exceed requirement estimates for weanling pigs (NRC, 1998). The DDGS diet contained corn, soybean meal, and 20% DDGS. The concentrations of energy and nutrients in this diet were determined to be similar to those in the control diet (Table 3). The third diet (**DDGS-S**) was similar to the DDGS diet with the exception that 0.74% $CaSO_4$ (21.9% Ca and 16.2% S) was added to the diet. The inclusion of limestone was reduced as $CaSO_4$ was added to the diet to maintain a constant Ca concentration in all diets. It was calculated that 0.74% $CaSO_4$ would contribute 0.12% additional S to the diet, and the total concentration of S in the DDGS-S diet was calculated to be 0.34%. This concentration of S corresponds to the concentration of S that the diet would have contained if a source of DDGS containing 0.90% S had been used. It was, therefore, believed that the concentration of S in the DDGS-S diet was equal to the concentration of S that a diet containing 20% DDGS with 0.90% S would have contained. This level of S inclusion was chosen because the preexperimental analysis of DDGS from 35 ethanol plants showed that DDGS could contain between 0.30 and 0.90% S (as-fed basis). Inclusion of dicalcium phosphate was reduced in the diets containing DDGS compared with the control diet to maintain a constant concentration of digestible P in all diets.

Forty-eight weanling barrows with an average initial BW of 20.1 kg (SD = 2.2 kg) were used. Pigs were grouped into 8 blocks by initial BW and were randomly allotted to 3 treatment groups in a randomized complete block design using the experimental animal allotment program (Kim and Lindemann, 2007). Two pigs were housed in each of 24 pens (1.1 × 1.9 m) that were equipped with 2 stainless steel feeders and a nipple drinker. Pigs had free access to feed and water during the entire 10-d experimental period.

In the first treatment group, 1 feeder contained the control diet and the other feeder contained the DDGS diet; in the second treatment group, 1 feeder contained the control diet and the other feeder contained the DDGS-S diet; and in the third treatment group, 1 feeder contained the DDGS diet and the other feeder contained the DDGS-S diet. Thus, all possible combinations of the 3 diets were offered. The positions of the 2 feeders within the pen were switched daily to mini-

Table 1. Sulfur concentrations (% of DM) in distillers dried grains with solubles[1]

Reference	Minimum	Maximum	Mean	SD	No. of samples	Analytical method[2]
Present experiment	0.33[3]	1.04[3]	0.65	0.19	35	TC
Lemenager et al., 2006	0.40	0.80	—	—	—	—
Kerr et al., 2008	0.34	1.25	0.64	0.21	19	TC
Kerr et al., 2008	0.38	1.35	0.69	0.23	19	ICP
Shurson, 2009	0.31	1.93[4]	0.69	0.26	49	—

[1]Content of 35 samples in the present experiment: CP, 30.5% (SD = 2.0); ether extract, 11.0% (SD = 1.4); NDF, 30.7% (SD = 3.0); and residual sugars, 7.9% (SD = 2.5) on a DM basis.

[2]TC = thermal combustion method; ICP = inductive coupled plasma spectroscopy method.

[3]On an as-fed basis, minimum and maximum S concentrations in 35 samples were 0.30 and 0.90%, respectively, in the present study.

[4]The second greatest value was 1.20%.

Table 2. Ingredient composition of the experimental diets,[1] as-fed basis

	Weanling pigs (Exp. 1 and 2)			Growing pigs (Exp. 3 and 4)			Finishing pigs (Exp. 4)		
Ingredient, %	Control	DDGS	DDGS-S	Control	DDGS	DDGS-S	Control	DDGS	DDGS-S
Ground corn	73.52	62.46	62.17	74.65	61.33	60.90	81.90	67.65	67.22
Soybean meal, 48% CP	23.00	14.00	14.00	23.00	6.00	6.00	16.00	—	—
DDGS[2]	—	20.00	20.00	—	30.00	30.00	—	30.00	30.00
L-Lys·HCl	0.33	0.54	0.54	—	0.43	0.43	—	0.40	0.40
DL-Met	0.08	0.05	0.05	—	—	—	—	—	—
L-Thr	0.10	0.11	0.11	—	0.03	0.03	—	—	—
L-Trp	0.02	0.05	0.05	—	0.04	0.04	—	0.05	0.05
Dicalcium phosphate	1.40	0.80	0.80	0.85	—	—	0.90	—	—
Ground limestone	0.85	1.29	0.84	0.80	1.47	0.80	0.50	1.20	0.53
$CaSO_4$	—	—	0.74	—	—	1.10	—	—	1.10
NaCl	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[3]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

[1]DDGS = distillers dried grains with solubles; and DDGS-S = DDGS-sulfur.

[2]The DDGS that was used contained the following nutrients (as-fed basis): CP, 25.80%; ADF, 9.98%; NDF, 32.78%; Ca, 0.02%; P, 0.68%, S, 0.30%; Arg, 1.09%; His, 0.71%; Ile, 0.99%; Leu, 2.88%; Lys, 0.77%; Met, 0.49%; Phe, 1.22%; Thr, 0.91%; Trp, 0.18%; Val, 1.27%. This source of DDGS also contained the following quantities of mycotoxins: aflatoxin, <5 μg/kg; fumonisins, <0.2 mg/kg; ochratoxin, <2 μg/kg; T-2 toxin, 73 μg/kg; vomitoxin, 0.5 mg/kg; and zearalenone, 66 μg/kg.

[3]The vitamin-micromineral premix provided the following quantities of vitamins and microminerals 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-α tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfate, 1.42 mg; thiamine 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.

mize positional preference. Feed allotments and feed disappearances were also recorded daily.

Exp. 2: Growth Performance, Weanling Pigs

In a 28-d experiment, a total of 90 weanling barrows with an average initial BW of 10.3 kg (SD = 1.4 kg) were allotted to 3 dietary treatments in a randomized complete block design with 10 blocks based on BW and 3 pigs per pen. Pigs were housed in 1.2 × 1.2 m fully slatted, plastic-coated metal floor pens. Each pen was equipped with a stainless steel feeder and a nipple drinker, and pigs had free access to feed and water throughout the experiment.

The diets that were used in Exp. 1 were also used in this experiment. Dietary treatments included the con-

Table 3. Analyzed composition of the experimental diets,[1] as-fed basis

	Weanling pigs (Exp. 1 and 2)			Growing pigs (Exp. 3 and 4)			Finishing pigs (Exp. 4)		
Item	Control	DDGS	DDGS-S	Control	DDGS	DDGS-S	Control	DDGS	DDGS-S
GE, cal/g	3,852	3,910	4,007	3,769	3,997	3,784	3,784	4,024	4,007
ME,[2] cal/g	3,292	3,308	3,298	3,330	3,348	3,333	3,342	3,361	3,347
CP, %	16.4	16.9	16.9	17.0	16.2	16.4	13.4	14.0	13.9
Arg, %	1.02	0.89	0.91	1.08	0.70	0.74	0.84	0.54	0.56
His, %	0.43	0.41	0.42	0.48	0.41	0.43	0.40	0.35	0.36
Ile, %	0.67	0.64	0.65	0.75	0.54	0.57	0.56	0.42	0.44
Leu, %	1.41	1.56	1.58	1.57	1.54	1.64	1.28	1.34	1.43
Lys, %	1.11	1.11	1.16	0.92	0.89	0.83	0.70	0.61	0.75
Met, %	0.32	0.32	0.33	0.27	0.26	0.27	0.22	0.23	0.24
Phe, %	0.76	0.75	0.77	0.86	0.65	0.73	0.68	0.56	0.59
Thr, %	0.68	0.67	0.69	0.62	0.51	0.56	0.51	0.43	0.45
Trp, %	0.21	0.22	0.21	0.21	0.18	0.18	0.16	0.16	0.16
Val, %	0.78	0.78	0.80	0.84	0.69	0.72	0.65	0.57	0.59
Ether extract, %	2.31	3.44	3.64	2.34	4.18	4.43	2.46	4.01	4.58
NDF, %	7.39	12.66	12.06	9.34	15.85	16.89	9.67	15.99	16.70
ADF, %	2.73	3.88	3.79	2.52	4.52	4.14	2.71	4.06	4.16
Ca, %	0.76	0.79	0.82	0.58	0.76	0.67	0.54	0.65	0.51
P, %	0.62	0.57	0.55	0.49	0.40	0.40	0.48	0.39	0.37
S, %	0.21	0.22	0.32	0.17	0.19	0.38	0.14	0.16	0.37

[1]Diets fed to weanling, growing, and finishing pigs were formulated to contain 1.03, 0.78, and 0.60% standardized ileal digestible Lys and 0.19, 0.15, and 0.13% standardized ileal digestible Trp. DDGS = distillers dried grains with solubles; and DDGS-S = DDGS-sulfur.

[2]Values for ME were calculated (NRC, 1998) rather than analyzed.

trol diet, the DDGS diet, and the DDGS-S diet. Daily feed allotments were recorded, and individual pig BW and feed left in the feeders were recorded on d 0, 14, and 28.

Exp. 3: Feed Preference, Growing Pigs

In a 10-d feed preference experiment, 30 growing barrows with an average initial BW of 49.6 kg (SD = 2.3) were used. Pigs were grouped into 10 blocks by initial BW and were randomly allotted to 3 treatment groups in a randomized complete block design. Pigs were individually housed in concrete slatted 2.6 × 3.7 m pens that were equipped with 2 stainless steel feeders and 2 nipple drinkers. Pigs had free access to feed and water.

Three grower diets were formulated (Table 2). The control diet consisted of ground corn and dehulled soybean meal supplemented with minerals and vitamins. The DDGS diet included corn, soybean meal, and 30% DDGS, and the concentrations of energy and nutrients in this diet were calculated to be similar to that in the control diet (Table 3). The last diet, the DDGS-S diet, was similar to the DDGS diet with the exception that 1.10% $CaSO_4$ was included in the diet. At this inclusion level, it was calculated that $CaSO_4$ contributed 0.18% S and the total concentration of S in the diet was calculated to be 0.375%. This level of S corresponds to the S that the diet would have contained if a source of DDGS with 0.90% S had been used. All experimental procedures were similar to those explained for Exp. 1.

Exp. 4: Growth Performance, Growing-Finishing Pigs

A total of 120 growing barrows with an average initial BW of 34.2 kg (SD = 2.3 kg) were allotted to 3 dietary treatments, with 4 pigs per pen and 10 pen replicates per treatment in a randomized complete block design. Pigs were housed in concrete slatted 1.9 × 2.6 m pens that were equipped with a stainless steel feeder and a nipple drinker. Pigs had free access to feed and water throughout the experiment. Pigs were fed grower diets during the initial 42 d of the experiment and finishing diets during the final 42 d of the experiment.

Dietary treatments included the control diet, the DDGS diet, and the DDGS-S diet. The grower diets were the same as those used in Exp. 3, and finisher diets were similar to the grower diets with the exception that less soybean meal and more ground corn were used (Table 2). Feed allotments were recorded daily, and pig BW and feed left in the feeders were recorded on d 0, 42, and 84.

Chemical Analysis

The same batch of DDGS was used in all diets. All samples of DDGS and all diets were ground through a 1-mm screen in a Wiley mill (model 4, Thomas Scientific, Swedesboro, NJ) and analyzed for GE using an adiabatic bomb calorimeter (Model 6300, Parr Instruments, Moline, IL). Samples were also analyzed for CP (method 930.15; AOAC International, 2007) using an Elementar Rapid N-Cube protein/N apparatus (Elementar Americas Inc., Mt. Laurel, NJ). The concentration of AA was analyzed on an AA analyzer (Model L8800, Hitachi High Technologies America, Inc., Pleasanton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Before analysis, samples were hydrolyzed with 6 *N* HCl for 24 h at 110°C (method 982.30 E; AOAC International, 2007). Methionine and Cys were analyzed as Met sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis. Tryptophan was determined after NaOH hydrolysis for 22 h at 110°C. Ether extract was assayed using the petroleum ether extraction method (method 2003.06; AOAC International, 2007) on an automated analyzer (Soxtec 2050, Foss North America, Eden Prairie, MN). Samples were also analyzed for ADF (method 973.18; AOAC International, 2007) and NDF (Holst, 1973). Calcium and P concentrations were determined using atomic absorption spectroscopy (method 968.08; AOAC International, 2007) and inductively coupled plasma spectroscopy (method 975.03; AOAC International, 2007), respectively, and S was analyzed using a combustion method. The DDGS sample was analyzed for aflatoxin, fumonisin, T-2 toxins, ochratoxin, and vomitoxin using the ELISA-Neogen method (Neogen Corp., Lansing, MI), and zearalenone in DDGS was also analyzed (method 994.01; AOAC International, 2007).

Calculation and Statistical Analysis

In the feed preference experiments (Exp. 1 and 3), feed preference for each diet was calculated using the following equation (Solà-Oriol et al., 2009):

$$\text{preference (\%)} = [\text{intake of the individual diet (kg)}/\text{intake of both diets (kg)}] \times 100.$$

Data from the preference experiments were analyzed by the paired *t*-test (SAS Inst. Inc., Cary, NC). In Exp. 3, 2 outliers were detected by the UNIVARIATE procedure in SAS and were removed from the data. The ADG of these outliers (data not shown) deviated by 1.9 and 2.9 times the interquartile ranges from the median of the group, whereas ADG of all other pigs were within 1.5 times the interquartile range.

Growth performance data from Exp. 2 and 4 were analyzed using MIXED procedures of SAS. The model included treatment as the fixed variable and block as the random variable. The UNIVARIATE procedure was used to analyze for outliers, but no outliers were identified. In Exp. 2, 3 pigs were removed from the experiment because of growth retardation that was unrelated to the dietary treatment. The feed intake of the remaining pigs in the same pen was estimated using the model developed by Lindemann and Kim (2007). In Exp. 4, 1 pig died on d 59, and data for the remaining pigs in the pen were also adjusted as described by Lindemann and Kim (2007). Least squares means of treatments were compared in a pair-wise manner using the PDIFF option of SAS. The differences among treatment groups were converted to letter groupings using the PDMIX800 macro in SAS (Saxton, 1998). Each pen was considered the experimental unit in all analyses, and an α-level of 0.05 was used for determination of significance among means.

RESULTS

Exp. 1: Feed Preference, Weanling Pigs

In the 10-d experimental period, a lesser preference ($P < 0.05$) for the DDGS diet and the DDGS-S diet compared with the control diet was observed for 4 d in each group (Table 4). Although pigs consumed less ($P < 0.05$) of the DDGS-S diet than of the DDGS diet on d 1, no preference difference was observed between these diets on the other days.

On a cumulative basis, the reduced feed preference for the DDGS diet compared with the control diet was significant ($P < 0.05$) on d 4, 9, and 10, and the reduced feed preference for the DDGS-S diet compared with the control diet was significant ($P < 0.05$) on d 9 and 10. During the overall 10-d period, the feed preferences for the DDGS diet and the DDGS-S diet compared with the control diet were 35.2 and 32.6%, respectively ($P < 0.05$). However, the feed preference was not different between the DDGS diet and the DDGS-S diet.

Exp. 2: Growth Performance, Weanling Pigs

From d 0 to 14, pigs fed the control diet gained more BW ($P < 0.05$) and had greater G:F ($P < 0.05$) compared with pigs fed the DDGS diet or the DDGS-S diet (Table 5). From d 14 to 28, pigs fed the control diet also had greater ADG ($P < 0.05$) than pigs fed the DDGS-S diet and had greater G:F ($P < 0.05$) than pigs fed the DDGS diet or the DDGS-S diet. During the overall period from d 0 to 28, pigs fed the control diet gained more BW ($P < 0.05$) and had greater G:F ($P < 0.05$) compared with pigs fed the DDGS or the DDGS-S diet, respectively. There were, however, no differences in ADFI among treatment groups, and no differences between pigs fed the DDGS and the DDGS-S diets were observed.

Exp. 3: Feed Preference, Growing Pigs

On a daily basis, reduced preferences ($P < 0.05$) for the DDGS diet and the DDGS-S diet compared with the control diet were observed for 7 and 8 d, respectively, during the 10-d experiment (Table 6). Although pigs tended to consume less ($P = 0.06$) of the DDGS-S diet than of the DDGS diet on d 3, no preference difference was observed between these diets on any of the other days.

On a cumulative basis, preference for the control diet was greater ($P < 0.05$) than preferences for the DDGS diet and the DDGS-S diet from d 2 to the conclusion of the experiment. During the overall period, feed preferences for the DDGS diet and the DDGS-S diet compared with the control diet were 29.8 and 32.9%, respectively ($P < 0.01$). However, feed preference was not different between the DDGS diet and the DDGS-S diet.

Exp. 4: Growth Performance, Growing-Finishing Pigs

From d 0 to 42, pigs fed the control diet gained more BW ($P < 0.05$) than pigs fed the DDGS diet and the DDGS-S diet (Table 7). The ADFI for pigs fed the control diet was greater ($P < 0.05$) than the ADFI of pigs fed the DDGS diet, and G:F of pigs fed the control diet was greater ($P < 0.05$) than that for pigs fed the DDGS-S diet. From d 42 to 84, pigs fed the control diet had greater ADG ($P < 0.05$) and G:F ($P < 0.05$) than pigs fed the DDGS-S diet. During the overall period, pigs fed the control diet gained more BW ($P < 0.05$) and had greater G:F ($P < 0.05$) than pigs fed the DDGS or the DDGS-S diet. Pigs fed the control diet also had greater ADFI ($P < 0.05$) than pigs fed the DDGS diet. Differences in BW, ADG, ADFI, or G:F between pigs fed the DDGS and the DDGS-S diets were not observed in the growing, finishing, or overall period.

DISCUSSION

Sulfur is present in DDGS because the corn kernel contains approximately 0.1% S (Kerr et al., 2008), and because of the removal of most of the starch during ethanol production, S is expected to be concentrated by a factor of 3 in DDGS. In addition, sulfuric acid is sometimes used in dry-grind ethanol production for pH adjustment, which results in S concentrations between approximately 0.3 and 0.9% (as-fed basis) in DDGS. In the 35 samples of DDGS that were analyzed before initiating the animal experiments reported here, the concentration of S in DDGS varied from 0.33 to 1.04% (DM basis), and this range is in agreement with previously reported data (Lemenager et al., 2006; Kerr et al., 2008; Shurson, 2009). The DDGS that was used in the present experiment was selected from an ethanol plant that does not use sulfuric acid, and the analyzed concentration of S in this source of DDGS (0.30%, as-fed basis) indicated that all the S came from the corn grain. By using this source of DDGS both without and with added S, we attempted to separate the effects of S and other effects of including DDGS in the diets.

Feed Preference (Exp. 1 and 3)

The preference of pigs to consume the corn- and soybean meal-based control diet instead of the diets con-

Table 4. Daily and cumulative feed preference of nursery pigs,[1,2] Exp. 1

	Group 1				Group 2				Group 3			
Item	Control	DDGS	SEM	*P*-value	Control	DDGS-S	SEM	*P*-value	DDGS	DDGS-S	SEM	*P*-value
Feed preference based on daily feed intake, %												
d 1	50.3	49.7	22.3	0.99	49.5	50.5	18.2	0.97	71.0	29.0	11.3	0.04
d 2	55.2	44.8	10.2	0.49	49.8	50.2	10.2	0.97	50.2	49.8	7.8	0.98
d 3	64.5	35.5	9.8	0.08	69.6	30.4	16.9	0.15	63.2	36.8	17.5	0.32
d 4	78.7	21.3	6.7	<0.01	64.9	35.1	13.7	0.17	61.4	38.6	10.7	0.18
d 5	57.5	42.5	16.3	0.54	70.7	29.3	11.2	0.04	49.9	50.1	17.5	0.99
d 6	63.0	37.0	12.0	0.17	75.7	24.3	10.8	0.01	59.1	40.9	15.7	0.44
d 7	60.3	39.7	16.9	0.42	62.0	38.0	15.2	0.30	45.6	54.4	21.4	0.78
d 8	70.9	29.1	11.2	0.03	71.2	28.8	13.5	0.06	56.9	43.1	18.2	0.61
d 9	72.5	27.5	8.6	<0.01	74.1	25.9	7.8	<0.01	54.8	45.2	16.2	0.69
d 10	73.9	26.1	11.0	0.02	82.0	18.0	4.6	<0.01	55.7	44.3	17.0	0.65
Feed preference based on cumulative feed intake, %												
d 1	50.3	49.7	22.3	0.99	49.5	50.5	18.2	0.97	71.0	29.0	11.3	0.04
d 2	52.0	48.0	12.0	0.82	48.4	51.6	10.4	0.83	55.9	44.1	6.4	0.23
d 3	55.5	44.5	8.6	0.40	54.4	45.6	11.6	0.60	56.7	43.3	6.0	0.15
d 4	61.8	38.2	6.3	0.03	57.4	42.6	10.3	0.35	58.5	41.5	6.8	0.12
d 5	60.6	39.4	8.0	0.10	60.3	39.7	8.9	0.15	57.0	43.0	8.3	0.27
d 6	61.4	38.6	7.3	0.06	63.4	36.6	8.3	0.06	57.2	42.8	9.5	0.32
d 7	61.1	38.9	8.3	0.10	62.8	37.2	8.5	0.07	55.8	44.2	10.8	0.48
d 8	62.5	37.5	7.6	0.05	64.0	36.0	8.9	0.06	55.8	44.2	11.7	0.51
d 9	63.8	36.2	7.5	0.04	65.1	34.9	8.4	0.04	55.5	44.5	11.9	0.53
d 10	64.8	35.2	7.6	0.03	67.4	32.6	7.3	0.01	55.5	44.5	12.2	0.54

[1]Each least squares mean represents 8 observations.

[2]Two different diets were provided in 2 feeders in each pen, and the positions of the 2 feeders within the pen were switched daily. DDGS = distillers dried grains with solubles; and DDGS-S = DDGS-sulfur.

Table 5. Growth performance of nursery pigs fed the experimental diets,[1,2] Exp. 2

Diet	Control	DDGS	DDSG-S	SEM	*P*-value
d 0 to 14					
Initial BW, kg	10.4	10.4	10.4	0.5	0.47
ADG, g/d	390[a]	296[b]	292[b]	14	<0.01
ADFI, g/d	713	668	719	28	0.35
G:F	0.550[a]	0.444[b]	0.408[b]	0.015	<0.01
Final BW, kg	15.8[a]	14.6[b]	14.5[b]	0.6	<0.01
d 14 to 28					
ADG, g/d	603[a]	549[ab]	541[b]	23	0.04
ADFI, g/d	1,134	1,132	1,122	43	0.97
G:F	0.535[a]	0.486[b]	0.484[b]	0.013	0.02
Final BW, kg	24.3[a]	22.3[b]	22.0[b]	0.8	<0.01
d 0 to 28					
ADG, g/d	497[a]	423[b]	416[b]	16	<0.01
ADFI, g/d	924	901	920	33	0.82
G:F	0.540[a]	0.471[b]	0.455[b]	0.012	<0.01

[a,b]Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Each least squares mean represents 10 pens of 3 pigs per pen.

[2]DDGS = distillers dried grains with solubles; and DDGS-S = DDGS-sulfur.

taining DDGS was evident based on cumulative feed preference. This response in feed preference was more apparent and instant in growing pigs than in weanling pigs, but this may be a consequence of the reduced DDGS in the diets fed to weanling pigs compared with the diets fed to growing pigs. In other experiments with weanling pigs, differences in feed preference were detectable after 1 or 2 d (Solà-Oriol et al., 2009; Seabolt et al., 2010), but in the present experiment, the preference based on the cumulative feed intake by weanling pigs of the control diet was significant only on d 4, 8, 9, and 10 of the experiment. Nevertheless, the data from the weanling pigs are in agreement with those of Seabolt et al. (2010), who observed a linear reduction in the preference for DDGS containing diets as DDGS inclusion increased from 0 to 30%.

A possible reason for the reduced feed preference for the DDGS diets may be the greater concentration of fiber in these diets compared with the control diet. In a recent experiment by Solà-Oriol et al. (2009), pigs had a reduced preference for oats (8.5% crude fiber) compared with other cereal grains, but the preference was improved when husks of the oats were removed, which resulted in oats with 1.0% crude fiber. The DDGS used in the present study contained 32.80% NDF and 9.98% ADF, and the diets containing DDGS, therefore, contained more ADF and NDF than the control diets. Thus, the greater fiber contents in DDGS may have contributed to the reduced preference for the DDGS diets.

Pigs are highly sensitive to vomitoxin, and the pigs may have reduced feed intake of diets containing 2 to 3 mg/kg of vomitoxin compared with diets containing no vomitoxin (van Heugten, 2001). However, the DDGS that was used in the present experiment contained only 0.5 mg/kg of vomitoxin, and other mycotoxins were also present at levels that would not be expected to influence acceptability of the diets (van Heugten, 2001). It is, therefore, unlikely that mycotoxins contributed to the reduced feed preference of the DDGS-containing diets.

The fact that feed preference was not different between pigs fed the DDGS diets and the DDGS-S diets indicates that dietary S did not influence the preference of diets fed to weanling or growing pigs. On the basis of this observation, it may be concluded that it is unlikely that the concentration of S in DDGS contributes to the reduced feed preference for diets containing DDGS. However, in agreement with previous research, results from the present experiments indicate that if given a choice, pigs prefer to eat corn-soybean meal diets rather than corn-soybean meal-DDGS diets.

Growth Performance (Exp. 2 and 4)

In 18 previous experiments with growing-finishing pigs fed diets containing DDGS, ADG was not affected by DDGS, but reduced ADG was observed in 6 experiments if DDGS was included in the diet (Stein and Shurson, 2009). It was suggested that reduced growth performance in some experiments may be a result of the relatively poor quality of DDGS used in those experiments. In the present study, we intended to formulate diets to provide similar concentrations of ME, CP, indispensable AA, Ca, and digestible P, and diet analyses did not indicate that concentrations of digestible nutrients in the DDGS-containing diets were less than in the control diets. It was also confirmed that the source of DDGS used did not contain mycotoxins in concentrations that would be expected to influence performance. It is possible that the relatively high concentration of fiber in DDGS may contribute to the reduced growth performance of pigs fed diets containing DDGS because dietary fiber increases the passage rate of digesta, which is negatively correlated with nutrient digestibility (Kass et al., 1980; Kim et al., 2007). However, in a recent experiment conducted in our laboratory, weanling pigs fed diets containing

Table 6. Daily and cumulative feed preference of growing pigs,[1,2] Exp. 3

	Group 1				Group 2				Group 3			
Item	Control	DDGS	SEM	*P*-value	Control	DDGS-S	SEM	*P*-value	DDGS	DDGS-S	SEM	*P*-value
Feed preference based on daily feed intake, %												
d 1	63.7	36.3	9.2	0.07	64.5	35.5	9.7	0.06	58.9	41.1	14.8	0.42
d 2	58.8	41.2	6.5	0.09	66.6	33.4	7.5	0.01	37.0	63.0	11.3	0.15
d 3	79.5	20.5	4.4	<0.01	63.0	37.0	7.2	0.03	63.7	36.3	8.5	0.06
d 4	69.1	30.9	10.7	0.03	65.0	35.0	6.3	<0.01	36.0	64.0	14.7	0.22
d 5	71.6	28.4	6.4	<0.01	56.7	43.3	13.0	0.49	53.0	47.0	14.1	0.77
d 6	70.0	30.0	7.7	<0.01	75.6	24.4	10.3	<0.01	44.2	55.8	17.8	0.66
d 7	69.9	30.1	10.8	0.03	68.6	31.4	10.8	0.04	39.1	60.9	11.4	0.22
d 8	71.5	28.5	11.7	0.03	67.7	32.3	9.9	0.03	32.4	67.6	16.4	0.17
d 9	65.5	34.5	12.6	0.11	70.7	29.3	12.5	0.04	47.1	52.9	18.2	0.83
d 10	77.6	22.4	12.7	0.01	71.2	28.8	8.5	<0.01	52.2	47.8	13.6	0.83
Feed preference based on cumulative feed intake, %												
d 1	63.7	36.3	9.2	0.07	64.5	35.5	9.7	0.06	58.9	41.1	14.8	0.42
d 2	61.5	38.5	6.7	0.04	65.2	34.8	7.0	0.01	46.7	53.3	10.6	0.68
d 3	67.9	32.1	4.0	<0.01	64.3	35.7	6.1	<0.01	52.2	47.8	8.4	0.72
d 4	68.3	31.7	4.4	<0.01	64.5	35.5	4.6	<0.01	48.3	51.7	8.2	0.78
d 5	69.1	30.9	4.3	<0.01	62.9	37.1	4.8	<0.01	49.4	50.6	8.8	0.92
d 6	69.1	30.9	3.9	<0.01	64.9	35.1	5.2	<0.01	48.1	51.9	8.7	0.77
d 7	69.2	30.8	4.6	<0.01	65.6	34.4	5.4	<0.01	47.1	52.9	8.0	0.62
d 8	69.7	30.3	4.7	<0.01	66.0	34.0	5.5	<0.01	45.3	54.7	7.7	0.41
d 9	69.2	30.8	5.3	<0.01	66.5	33.5	6.0	<0.01	45.4	54.6	7.5	0.42
d 10	70.2	29.8	5.8	<0.01	67.1	32.9	5.8	<0.01	46.3	53.7	7.9	0.53

[1]Each least squares mean represents 10 observations.

[2]Two different diets were provided in 2 feeders for each pig, and the positions of the 2 feeders within the pen were switched daily. DDGS = distillers dried grains with solubles; and DDGS-S = DDGS-sulfur.

Table 7. Growth performance of growing-finishing pigs fed the experimental diets,[1,2] Exp. 4

Item	Control	DDGS	DDSG-S	SEM	*P*-value
d 0 to 42					
Initial BW, kg	34.2	34.2	34.2	0.7	0.25
ADG, g/d	1,025[a]	915[b]	910[b]	20	<0.01
ADFI, g/d	2,722[a]	2,553[b]	2,586[ab]	62	0.02
G:F	0.377[a]	0.360[ab]	0.352[b]	0.007	0.01
Final BW, kg	77.3[a]	72.6[b]	72.4[b]	1.3	<0.01
d 42 to 84					
ADG, g/d	1,017[a]	909[ab]	904[b]	33	0.03
ADFI, g/d	3,385	3,221	3,317	67	0.21
G:F	0.300[a]	0.282[ab]	0.272[b]	0.006	0.01
Final BW, kg	120.0[a]	110.8[b]	110.4[b]	2.1	<0.01
d 0 to 84					
ADG, g/d	1,021[a]	912[b]	907[b]	20	<0.01
ADFI, g/d	3,054[a]	2,887[b]	2,951[ab]	54	0.04
G:F	0.335[a]	0.316[b]	0.307[b]	0.004	<0.01

[a,b]Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]Each least squares mean represents 10 pens of 4 pigs per pen.

[2]DDGS = distillers dried grains with solubles; and DDGS-S = DDGS-sulfur.

20% DDGS tended to have greater ADFI and ADG than pigs fed corn-soybean meal control diets (Almeida and Stein, 2010). It is, therefore, not clear why pigs fed the diets containing DDGS in the present experiments had reduced performance compared with pigs fed the control diets, but it is possible that the source of DDGS that was used had a below-average digestibility of AA because it has been reported that AA digestibility may vary among sources of DDGS (Stein et al., 2006; Stein and Shurson, 2009). Nevertheless, the fact that no differences between pigs fed the DDGS diets and pigs fed the DDGS-S diets were observed indicates that the concentration of dietary S does not influence the ADFI, ADG, or G:F of pigs fed DDGS containing diets. This observation is in agreement with the conclusions from the feed preference tests. Likewise, inclusion of up to 1.25% $CaSO_4$ in corn- and soybean meal-based diets fed to weanling and growing pigs does not influence pig growth performance (Kerr et al., 2011). As a consequence, we were not able to verify the hypothesis that the reduced preference for diets and the reduced performance of pigs fed diets containing DDGS, which are sometimes observed, were correlated with the concentration of S in the DDGS.

Conclusions

Inclusion of 20 and 30% DDGS in corn- and soybean meal-based diets fed to weanling and growing-finishing pigs, respectively, decreased the feed preference and negatively affected the growth performance of weanling and growing-finishing pigs. However, the concentration of S in the diets did not influence feed preference or growth performance, and as a consequence, it is unlikely that the variation in S concentration observed among samples of DDGS negatively influenced feed preference or pig growth performance. Likewise, it is unlikely that the different responses to inclusion of DDGS in diets fed to weanling and growing-finishing pigs, which have been observed in previous experiments, were caused by differences in S among the sources of DDGS used in these experiments.

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