Journal of Animal Science, 2021, Vol. 99, No. 8, 1–8

doi:10.1093/jas/skab129
Advance Access publication May 27, 2021
Received: 8 February 2021 and **Accepted:** 19 April 2021
Non Ruminant Nutrition

NON RUMINANT NUTRITION

Growth performance and carcass quality are not different between pigs fed diets containing cold-fermented low-oil DDGS and pigs fed conventional DDGS, but pelleting improves gain to feed ratio regardless of source of DDGS

Diego A. Rodriguez, Su A Lee, and Hans H. Stein[1]

Department of Animal Sciences, University of Illinois, Urbana 61801, IL, USA

[1]Corresponding author: hstein@illinois.edu

ORCiD numbers: 0000-0001-9351-7196 (S. A. Lee); 0000-0002-4855-661x (H. H. Stein); 0000-0002-3860-6353 (D. A. Rodriguez).

Abstract

The objective of this study was to test the hypothesis that growth performance and carcass characteristics of pigs fed diets containing cold-fermented, low oil distillers dried grains with solubles (**DDGS**) is not different from that of pigs fed diets containing conventional DDGS regardless of the physical form of the diets. A total of 160 barrows and gilts were used. There were 4 diets, 10 pens per diet, and 4 pigs per pen. Pigs were weaned at 21 d of age and fed a common phase 1 diet that did not contain DDGS during the initial 7 d post-weaning. Pigs were then allotted to the four diets that were arranged in a 2 × 2 factorial design with two sources of DDGS (cold-fermented and conventional DDGS) and two diet forms (meal and pellets). Pigs were fed phase 2 diets from day 7 to 21 and phase 3 diets from day 21 to 43 post-weaning. All diets were based on corn and soybean meal, but phase 2 diets also contained 15% DDGS and phase 3 diets contained 30% DDGS. From day 43, pigs were fed grower diets for 38 d, early finisher diets for 38 d, and late finisher diets for 18 d and these diets also contained 30% DDGS. Feed was provided on an ad libitum basis and daily feed allotments were recorded. Pigs were weighed at the beginning of each phase and at the conclusion of the experiment. On the last day of the experiment, the pig in each pen with a body weight that was closest to the pen average was slaughtered and carcass measurements were determined. Combined results for the two nursery phases indicated that feeding meal diets instead of pelleted diets increased ($P < 0.001$) average daily feed intake and decreased ($P < 0.05$) gain to feed ratio (**G:F**). However, no differences between the two sources of DDGS were observed for the overall growth performance of weanling pigs. For the entire growing-finishing period, the source of DDGS did not affect growth performance, but pigs fed meal diets had reduced ($P < 0.001$) G:F compared with pigs fed the pelleted diets. There were no differences between the two sources of DDGS for carcass characteristics. Back fat was greater ($P < 0.05$) for pigs fed pelleted diets than for pigs fed meal diets. In conclusion, no differences in growth performance or carcass characteristics between pigs fed cold-fermented DDGS and pigs fed conventional DDGS were observed. However, pigs fed pelleted diets had greater G:F and greater back fat than pigs fed meal diets.

Key words: carcass characteristics, distillers dried grains with solubles, growth performance, meal, pelleting, pigs

Abbreviations

AA	amino acids
ADFI	average daily feed intake
ADG	average daily gain
AEE	acid hydrolyzed ether extract
BW	body weight
CP	crude protein
DDGS	distiller dried grains with solubles
DM	dry matter
G:F	gain to feed ratio
HCW	hot carcass weight
ME	metabolizable energy
SID	standardized ileal digestible

Introduction

Corn distillers dried grains with solubles (**DDGS**), a co-product from the dry-grind ethanol industry, is commonly included in diets for pigs (Stein and Shurson, 2009). In most ethanol plants, oil is removed from the solubles resulting in less oil in DDGS produced now compared with what was produced 10 to 15 yr ago (NRC, 2012). Conventional DDGS contains more than 10% oil, whereas medium-oil DDGS contains 6% to 9% oil and low-oil DDGS contains less than 5% oil (NRC, 2012). Up to 30% conventional DDGS may be used in diets for growing-finishing pigs (Stein and Shurson, 2009), but inclusion rate may depend on the concentration of fat in DDGS (Wu et al., 2016).

Poet Nutrition (Sioux Falls, SD) uses a heat-free cold fermentation technique to produce a low-oil DDGS. This ingredient is produced using a technique called the Broin Project X, and the concentration of standardized ileal digestible (**SID**) amino acids (**AA**) in cold-fermented DDGS is greater than in conventional DDGS (Rodriguez et al., 2020). However, because of the reduced oil, the metabolizable energy (**ME**) in cold-fermented DDGS is less than in conventional DDGS. It is, however, not known how this will affect growth performance or carcass quality of pigs.

Pelleting of diets is often used to improve growth performance of weanling and growing-finishing pigs (Rojas and Stein, 2017), and specifically, pelleting increases gain to feed ratio (**G:F**; Lancheros et al., 2020), but there is limited information about effects of pelleting diets that contain cold-fermented DDGS. Therefore, the objective of this research was to test the hypothesis that including cold-fermented DDGS in meal diets or pelleted diets fed to pigs from weaning to market results in growth performance and carcass composition that are not different from that of pigs fed diets containing conventional DDGS.

Materials and Methods

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocol for the experiment. Pigs used in this experiment were the offspring of line 359 boars and Camborough females (Pig Improvement Company, Hendersonville, TN).

Animals, housing, diets, and feeding

A total of 160 barrows and gilts were weaned at 21 d of age (initial body weight [**BW**]: 7.87 ± 0.96 kg) and allotted to 40 pens with 4 pigs (2 gilts and 2 barrows) in each pen. Pigs were fed a common phase 1 diet for 7 d post-weaning and this diet did not contain DDGS. On day 8, pigs were allotted to the 4 experimental diets (10 pens per diet) that were arranged in a 2 × 2 factorial design with 2 sources of DDGS (cold-fermented and conventional DDGS; Table 1) and 2 diet forms (meal and pellets). Pigs were fed phase 2 diets from day 7 to 21 post-weaning and phase 3 diets from day 21 to 43 post-weaning (Tables 2 and 3). All diets were based on corn and soybean meal, but phase 2 diets also contained 15% DDGS and phase 3 diets contained 30% DDGS. Concentrations of SID AA in diets were calculated based on data for the two sources of DDGS that were obtained in a previous experiment (Rodriguez et al., 2020). All diets were formulated on an as-is basis and met current requirement estimates for weanling pigs (NRC, 2012), but no attempt to equalize ME between diets containing cold-fermented or conventional DDGS was made. As a consequence, the calculated ME in diets containing conventional DDGS was slightly greater than for diets containing cold-fermented DDGS because ME in conventional DDGS is greater than in cold-fermented DDGS (Rodriguez et al., 2020). Feed was provided on an ad libitum basis and water was available at all times. Pigs were weighed at the beginning of phase 2 and at the conclusion of phases 2 and 3. Daily feed allotments were recorded as well.

On day 43 post-weaning, pigs were moved to a growing-finishing facility, and they were fed grower diets for 38 d, early finisher diets for 38 d, and late finisher diets for 18 d. The dietary treatments in the nursery continued in the growing-finishing period with inclusion of 30% DDGS in all diets (Tables 4 and 5). Diets for the growing-finishing period were formulated as outlined for the nursery phase with SID AA being equal among

Table 1. Analyzed nutrient composition of cold-fermented and conventional distillers dried grains with solubles (DDGS), as-is basis

	Source of DDGS	
Item, %	Cold-fermented	Conventional
Gross energy, kcal/kg	4,430	4,516
DM	87.77	82.26
Ash	5.13	5.09
Crude protein	27.92	24.52
Acid hydrolyzed ether extract	6.80	8.92
Neutral detergent fiber	29.32	35.14
Acid detergent fiber	12.44	15.42
Total dietary fiber	34.8	36.9
Soluble dietary fiber	2.4	2.4
Insoluble dietary fiber	32.4	34.5
Indispensable AA		
Arg	1.28	1.15
His	0.78	0.66
Ile	1.14	1.07
Leu	3.30	2.95
Lys	0.96	0.79
Met	0.53	0.48
Phe	1.42	1.33
Thr	1.09	0.97
Trp	0.17	0.20
Val	1.44	1.33
Dispensable AA		
Ala	2.06	1.77
Asp	1.87	1.64
Cys	0.53	0.45
Glu	4.64	3.46
Gly	1.21	1.03
Pro	2.30	1.90
Ser	1.25	1.12
Tyr	1.04	0.94

Table 2. Ingredient composition of experimental diets for weanling pigs containing cold-fermented or conventional distillers dried grains with solubles (DDGS), as-fed basis

Ingredient, %	Phase 2		Phase 3	
DDGS:	Cold-fermented	Conventional	Cold-fermented	Conventional
Ground corn	36.50	36.43	35.28	33.75
Whey, dried	20.00	20.00	10.00	10.00
Soybean meal, 48% CP[1]	14.00	14.00	18.50	20.00
Cold-fermented DDGS	15.00	-	30.00	-
Conventional DDGS	-	15.00	-	30.00
Fish meal	6.00	6.00	-	-
Blood plasma	3.00	3.00	-	-
Soybean oil	3.50	3.50	3.50	3.50
$_{L-}$Lys·HCl	0.30	0.35	0.50	0.55
$_{DL-}$Met	0.05	0.05	0.05	0.05
$_{L-}$Thr	-	0.02	0.05	0.05
$_{L-}$Trp	-	-	0.02	-
Ground limestone	0.95	0.95	1.40	1.40
Dicalcium phosphate	-	-	-	-
Sodium chloride	0.40	0.40	0.40	0.40
Vit-min premix[2]	0.30	0.30	0.30	0.30

[1]CP, crude protein.
[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kg of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D_3 as cholecalciferol, 2,208 IU; vitamin E as $_{DL-}$alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 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, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

Table 3. Analyzed composition of experimental diets containing corn distillers dried grains with solubles (DDGS) for weanling pigs, as-fed basis

Item, %	Phase 2[1]				Phase 3[1]			
DDGS:	Cold-fermented		Conventional		Cold-fermented		Conventional	
Diet form:	Meal	Pellet	Meal	Pellet	Meal	Pellet	Meal	Pellet
Gross energy, kcal/kg	4,202	4,107	4,173	4,118	4,221	4,082	4,229	3,960
ME[2], kcal/kg	3,441	3,441	3,447	3,447	3,283	3,283	3,295	3,295
DM	91.00	89.64	91.22	90.17	91.21	88.35	87.21	86.27
Crude protein	22.61	22.71	22.20	21.72	20.75	22.19	22.02	21.29
Ash	5.94	6.11	6.59	6.28	5.98	5.85	5.62	5.44
AEE[3]	4.20	4.10	4.34	3.91	4.13	6.11	7.27	5.91
Indispensable AA[1]								
Arg	1.25	1.14	1.22	1.15	1.16	1.21	1.22	1.14
His	0.58	0.54	0.57	0.54	0.56	0.58	0.57	0.54
Ile	0.98	0.92	0.96	0.92	0.95	0.98	0.96	0.91
Leu	2.03	1.94	1.99	1.89	2.09	2.12	2.06	2.00
Lys	1.62	1.49	1.61	1.49	1.44	1.46	1.53	1.41
Met	0.43	0.40	0.42	0.40	0.38	0.39	0.37	0.37
Phe	1.08	1.02	1.05	0.99	1.06	1.09	1.00	0.96
Thr	0.99	0.94	0.99	0.93	0.90	0.91	0.91	0.89
Trp	0.29	0.29	0.31	0.28	0.27	0.28	0.29	0.29
Val	1.18	1.10	1.16	1.11	1.09	1.12	1.11	1.06
Dispensable AA								
Ala	1.26	1.20	1.23	1.18	1.26	1.26	1.23	1.21
Asp	2.08	1.94	2.04	1.93	1.86	1.93	1.94	1.82
Cys	0.42	0.40	0.39	0.39	0.39	0.41	0.38	0.38
Glu	3.62	3.40	3.46	3.30	3.62	3.69	3.54	3.44
Gly	0.98	0.96	0.98	0.93	0.86	0.90	0.89	0.86
Pro	1.32	1.27	1.27	1.24	1.43	1.42	1.36	1.32
Ser	0.97	0.91	0.95	0.89	0.89	0.92	0.93	0.89
Tyr	0.76	0.71	0.73	0.69	0.74	0.76	0.68	0.67

[1]Phase 2 diets were formulated to contain 1.36, 0.40, 0.79, and 0.23% standardized ileal digestible Lys, Met, Thr, and Trp, respectively. Phase 3 diets were formulated to contain 1.23, 0.37, 0.74, and 0.21% standardized ileal digestible Lys, Met, Thr, and Trp, respectively.
[2]Concentrations of metabolizable energy (ME) in diets were calculated rather than analyzed. For the 2 sources of DDGS, ME was from Rodriguez et al. (2020) and for all other ingredients, ME was from NRC (2012).
[3]AEE, acid hydrolyzed ether extract.

Table 4. Ingredient composition of experimental diets for growing-finishing pigs containing cold-fermented or conventional distillers dried grains with solubles (DDGS), as-fed basis

Ingredient, %	Growing		Early finishing		Late finishing	
DDGS:	Cold-fermented	Conventional	Cold-fermented	Conventional	Cold-fermented	Conventional
Ground corn	49.48	49.37	54.85	54.76	57.12	57.03
Soybean meal, 48% CP[1]	17.00	17.00	12.00	12.00	10.00	10.00
Cold-fermented DDGS	30.00	-	30.00	-	30.00	-
Conventional DDGS	-	30.00	-	30.00	-	30.00
Choice white grease	1.00	1.00	1.00	1.00	1.00	1.00
$_{L}$-Lys·HCl	0.31	0.40	0.22	0.31	0.13	0.22
Ground limestone	1.36	1.38	1.23	1.23	1.05	1.05
Dicalcium phosphate	0.15	0.15	-	-	-	-
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40
Vit-min premix[2]	0.30	0.30	0.30	0.30	0.30	0.30

[1]CP, crude protein.
[2]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kg of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D_3 as cholecalciferol, 2,208 IU; vitamin E as $_{DL}$-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 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, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

Table 5. Analyzed composition of experimental diets containing distillers dried grains with solubles (DDGS) for growing-finishing pigs, as-fed basis

Item, %	Growing[1]				Early finishing[1]				Late finishing[1]			
DDGS:	Cold-fermented		Conventional		Cold-fermented		Conventional		Cold-fermented		Conventional	
Diet form:	Meal	Pellet	Meal	Pellet	Meal	Pellet	Meal	Pellet	Meal	Pellet	Meal	Pellet
DM	90.20	87.56	89.22	87.72	89.79	87.42	89.01	86.95	88.91	87.65	88.37	86.51
Gross energy, kcal/kg	4,085	3,981	4,043	3,990	4,012	3,969	4,074	3,942	4,014	3,955	4,028	3,965
ME[2], kcal/kg	3,154	3,154	3,165	3,165	3,167	3,167	3,179	3,179	3,175	3,175	3,186	3,186
Crude protein	21.33	20.86	20.21	19.96	18.98	18.54	17.97	18.03	17.34	18.04	16.83	16.20
Ash	5.60	4.74	5.06	5.60	4.78	4.67	4.47	4.53	4.44	4.19	4.52	4.16
AEE[3]	5.18	4.69	5.24	5.42	5.14	5.79	5.69	5.92	5.45	4.92	5.21	5.49
Indispensable AA												
Arg	1.15	1.15	1.18	1.12	1.07	1.06	1.03	1.00	0.88	0.91	0.85	0.82
His	0.57	0.56	0.55	0.53	0.53	0.52	0.50	0.49	0.47	0.47	0.43	0.42
Ile	0.90	0.88	0.88	0.85	0.81	0.83	0.79	0.77	0.71	0.72	0.70	0.70
Leu	2.05	2.01	1.98	1.93	1.93	1.91	1.85	1.80	1.78	1.80	1.69	1.69
Lys	1.26	1.19	1.29	1.19	1.05	1.04	1.07	1.06	0.85	0.83	0.86	0.85
Met	0.33	0.33	0.34	0.33	0.34	0.33	0.32	0.31	0.30	0.28	0.30	0.27
Phe	1.05	1.03	1.05	1.01	0.98	0.98	0.88	0.86	0.86	0.88	0.85	0.85
Thr	0.78	0.79	0.80	0.77	0.75	0.73	0.69	0.69	0.65	0.66	0.65	0.64
Trp	0.23	0.25	0.24	0.22	0.21	0.21	0.22	0.22	0.18	0.22	0.19	0.18
Val	1.04	1.02	1.04	0.99	0.96	0.98	0.96	0.93	0.85	0.85	0.83	0.86
Dispensable AA												
Ala	1.27	1.23	1.21	1.16	1.21	1.18	1.14	1.11	1.11	1.11	1.03	1.03
Asp	1.75	1.77	1.79	1.74	1.61	1.62	1.53	1.51	1.35	1.37	1.39	1.36
Cys	0.37	0.39	0.38	0.35	0.39	0.37	0.33	0.34	0.33	0.32	0.35	0.29
Glu	3.59	3.54	3.38	3.30	3.31	3.30	3.07	3.07	2.92	2.96	2.76	2.76
Gly	0.87	0.85	0.87	0.83	0.82	0.81	0.80	0.78	0.74	0.74	0.70	0.70
Pro	1.41	1.39	1.36	1.31	1.37	1.37	1.24	1.23	1.26	1.24	1.18	1.14
Ser	0.89	0.88	0.89	0.87	0.84	0.78	0.76	0.78	0.70	0.73	0.71	0.72
Tyr	0.69	0.71	0.72	0.68	0.67	0.66	0.59	0.57	0.59	0.63	0.59	0.53

[1]Grower diets were formulated to contain 0.98, 0.32, 0.64, and 0.17% standardized ileal digestible Lys, Met, Thr, and Trp, respectively. Early finisher diets were formulated to contain 0.79, 0.30, 0.57, and 0.14% standardized ileal digestible Lys, Met, Thr, and Trp, respectively. Late finisher diets were formulated to contain 0.67, 0.29, 0.54, and 0.13% standardized ileal digestible Lys, Met, Thr, and Trp, respectively.
[2]Concentrations of metabolizable energy (ME) in diets were calculated rather than analyzed. For the 2 sources of DDGS, ME was from Rodriguez et al. (2020) and for all other ingredients, ME was from NRC (2012).
[3]AEE, acid hydrolyzed ether extract.

diets within each phase, whereas ME in diets was allowed to vary based on the source of DDGS that was used. Daily feed allotments were recorded and individual pig weights were recorded on the last day of each phase.

On the last day of the experiment, the pig in each pen that had a BW that was closest to the pen average was transported to the Meat Science Laboratory at the University of Illinois and slaughtered after an overnight fast. Half of the slaughtered pigs were barrows and the other half were gilts and the number of barrows and gilts was balanced within dietary treatments. Standard carcass measurements (i.e., hot carcass weight [**HCW**], dressing percentage, back fat thickness, and loin eye area) were determined after slaughter.

Data for pig weights and feed consumption were summarized at the conclusion of the experiment and average daily gain (**ADG**), average daily feed intake (**ADFI**), and G:F were calculated for each treatment and summarized within phase. Data for carcass characteristics were also summarized within treatment and average carcass fat-free leanness was calculated for each treatment based on NPPC (1999).

Chemical analysis

At each diet mixing, approximately 5 kg of each diet was collected and before analysis, diet samples were mixed and subsampled. Samples of the two sources of DDGS were collected as well. All analyses were in duplicate. Ingredient and diet samples were analyzed for gross energy using bomb calorimetry (Model 6400, Parr Instruments, Moline, IL), dry matter (**DM**; Method 930.15; AOAC, 2007), and N (method 990.03; AOAC, 2007) and crude protein was calculated as N × 6.25. Acid hydrolyzed ether extract was analyzed using the acid hydrolysis filter bag technique (Ankom HCl Hydrolysis System, Ankom Technology, Macedon, NY) followed by fat extraction (Ankom XT-15 Extractor, Ankom Technology, Macedon, NY). Diet and ingredient samples were analyzed for ash (method 942.05; AOAC, 2007). Acid detergent fiber and neutral dietary fiber (Ankom 2000 Fiber Analyzer, Ankom Technology, Macedon, NY) also were analyzed for the two sources of DDGS. The two sources of DDGS were analyzed for insoluble and soluble dietary fiber using the Ankom Dietary Fiber Analyzer (Ankom Technology, Macedon, NY; method 991.43, AOAC Int., 2007). Total dietary fiber was calculated as the sum of concentrations of soluble and insoluble dietary fibers.

Amino acids in the two sources of DDGS and all diets were analyzed on a Hitachi Amino Acid Analyzer, Model No. L8800 (Hitachi High Technologies America, Inc; Pleasanton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Prior to analysis, samples were hydrolyzed with 6*N* HCl for 24 h at 110 °C (method 982.30 E[a]; AOAC, 2007). Methionine and Cys were determined as Met sulfone and cysteic acid after cold performic acid oxidation overnight before hydrolysis (method 982.30 E[b]; AOAC, 2007). Tryptophan was determined after NaOH hydrolysis for 22 h at 110 °C (method 982.30 E[c]; AOAC, 2007).

Statistical analyses

Data were analyzed as a 2 × 2 factorial using the PROC MIXED procedure in SAS. The initial model included source of DDGS, diet form, and the interaction between source of DDGS and diet form as the fixed effects. However, the interaction between source of DDGS and diet form was not significant for any response variables and the interaction was, therefore, eliminated from the final model and only main effects are presented. Hot carcass weight was used as a co-variate for analysis of the carcass data. The pen was the experimental unit for growth performance data and pig was the experimental unit for carcass characteristics. Least square means were calculated for each independent variable. Results were considered significant at $P < 0.05$ and considered a trend at $P < 0.10$.

Results

Pigs remained healthy and consumed their diets without apparent problems. Overall, two pigs died during the experiment; these pigs were fed the cold-fermented DDGS diet in meal form (phase 2 of the nursery period) and the conventional DDGS in the pelleted form (early finishing period), respectively. Two additional pigs that were fed the pelleted conventional DDGS diet (early finishing period) and the pelleted cold-fermented DDGS diet (late finishing period), respectively, were removed from the study because of leg problems. Data for the pens where these four pigs were housed were adjusted using the partitioning method (Lindemann and Kim, 2007; Lee et al., 2016).

Growth performance

During phase 2 of the nursery period, pigs that were fed diets containing conventional DDGS tended ($P < 0.10$) to have increased ADG and final BW compared with pigs that were fed diets containing cold-fermented DDGS (Table 6). Values for G:F were also greater ($P < 0.05$) for pigs fed diets containing conventional

Table 6. Growth performance of weanling pigs fed experimental diets containing cold-fermented or conventional distillers dried grains with solubles (DDGS)[1,2]

Item[3]	Source of DDGS		Diet form			P-value	
Diet form:	Cold-fermented	Conventional	Meal	Pellet	Pooled SEM	DDGS	Diet form
Nursery phase 2 (day 8–21)							
Initial body weight, kg	7.87	7.88	7.86	7.88	-	-	-
ADG[3], kg	0.37	0.39	0.40	0.36	0.01	0.076	0.002
ADFI[3], kg	0.51	0.51	0.53	0.49	0.02	0.967	0.002
G:F[3]	0.72	0.76	0.75	0.73	0.01	0.020	0.366
Final body weight, kg	12.98	13.30	13.42	12.87	0.49	0.076	0.003
Nursery phase 3 (day 22–43)							
ADG, kg	0.65	0.64	0.64	0.64	0.02	0.568	0.964
ADFI, kg	1.05	1.08	1.10	1.03	0.03	0.178	<0.001
G:F	0.61	0.59	0.58	0.62	0.01	0.142	0.011
Final body weight, kg	27.19	27.31	27.53	26.96	0.83	0.757	0.146
Overall (day 8–43)							
ADG, kg	0.54	0.54	0.55	0.53	0.01	0.771	0.131
ADFI, kg	0.84	0.86	0.88	0.82	0.02	0.279	<0.001
G:F	0.64	0.63	0.62	0.65	0.01	0.547	0.030

[1]Each least squares mean represents 10 observations.
[2]Because the interaction between source of DDGS and diet form was not significant for any response variables ($P > 0.10$) only main effects of source of DDGS and diet form are shown.
[3]ADG, average daily gain; ADFI, average daily feed intake; G:F, gain to feed ratio.

DDGS compared with pigs fed diets containing cold-fermented DDGS. Pigs fed meal diets had greater ($P < 0.01$) ADG, ADFI, and final BW than pigs fed the pelleted diets during phase 2, but there was no difference in G:F between pigs fed pelleted and meal diets. In phase 3, no differences between the two sources of DDGS were observed for ADG, ADFI, G:F, or final BW, but pigs fed meal diets had greater ($P < 0.001$) ADFI and reduced ($P < 0.05$) G:F compared with pigs fed pelleted diets. Combined for the two nursery phases from day 7 to 43 post-weaning, feeding meal diets instead of pelleted diets increased ($P < 0.001$) ADFI and decreased ($P < 0.05$) G:F. However, no differences between the two sources of DDGS were observed for the overall growth performance of weanling pigs during this period.

In the grower phase, pigs fed diets containing conventional DDGS had greater ($P < 0.05$) ADG and ADFI and tended ($P < 0.10$) to have greater final BW than pigs fed cold-fermented DDGS (Table 7). Pigs fed meal diets also had greater ($P < 0.01$) ADG, ADFI, and final BW compared with pigs fed pelleted diets, but the G:F was reduced ($P < 0.05$) for pigs fed the meal diets compared with pigs fed diets that were pelleted.

In the early finishing period, there were no differences between pigs fed the 2 DDGS sources, but ADG and G:F of pigs fed pelleted diets were greater ($P < 0.01$) than for pigs fed meal diets. In late finishing, the source of DDGS in the diet did not influence pig growth performance, but pigs fed pelleted diets had greater ($P < 0.05$) G:F than pigs fed meal diets. For the entire growing-finishing period, the source of DDGS did not affect ADG, ADFI, or G:F of pigs, but pigs fed meal diets had reduced ($P < 0.001$) G:F compared with pigs fed the pelleted diets.

Carcass characteristic

There were no differences among pigs fed diets containing cold-fermented DDGS and pigs fed diets containing conventional DDGS for any of the carcass characteristics measured (Table 8). However, 10th rib back fat was greater ($P < 0.05$) for pigs fed pelleted diets than for pigs fed meal diets. There also was a tendency for lower ($P < 0.10$) HCW for pigs fed meal diets compared with pigs fed pelleted diets.

Discussion

The Broin Project X technology produces reduced-oil DDGS because in addition to using a proprietary enzyme blend in fermentation to convert starch to ethanol, the process used to remove oil from the solubles is more efficient than that used in production of conventional DDGS. As a consequence, the concentration of acid hydrolyzed ether extract (**AEE**) in cold-fermented DDGS is less than in conventional DDGS, and although the digestibility of AEE in DDGS is low (Kim et al., 2013), the concentration of ME in cold-fermented DDGS is less than in conventional DDGS (Rodriguez et al., 2020). Both sources of DDGS had DM that was less than indicated by NRC (2012), and specifically the conventional DDGS had a very low DM. The same batches of DDGS were used in our previous research where we measured digestibility of AA and gross energy (Rodriguez et al., 2020), and as a consequence, values for ME and SID AA used in diet formulations took the different DM concentrations in the two sources of DDGS into account. Because the difference in ME between the two sources of DDGS was small, diets were not formulated to be isoenergetic. However, if the DM had not been different between the two sources, the conventional DDGS would have contained approximately 220 kcal/kg more ME than the cold-fermented DDGS, which might have impacted the G:F in the experiment.

Growth performance

The overall growth performance of all pigs was excellent both during the nursery period and during the growing-finishing period indicating that acceptable growth performance of pigs may be obtained even if there is 30% DDGS in the diets. This

Table 7. Growth performance of growing-finishing pigs fed experimental diets containing cold-fermented or conventional distillers dried grains with solubles (DDGS)[1,2]

Item[3]	Source of DDGS		Diet form			P-value	
Diet form:	Cold-fermented	Conventional	Meal	Pellet	Pooled SEM	DDGS	Diet form
Growing (day 1–38)							
Initial body weight, kg	27.19	27.31	27.53	26.96	0.83	0.757	0.146
ADG[3], kg	0.87	0.90	0.91	0.87	0.02	0.040	0.009
ADFI[3], kg	1.85	1.92	1.95	1.81	0.04	0.026	<0.001
G:F[3]	0.47	0.47	0.47	0.48	0.01	0.986	0.032
Final body weight, kg	60.27	61.63	62.05	59.85	1.33	0.057	0.003
Early finishing (day 39–76)							
ADG, kg	1.00	0.99	0.96	1.03	0.02	0.832	0.002
ADFI, kg	2.81	2.85	2.84	2.82	0.05	0.517	0.747
G:F	0.36	0.35	0.34	0.37	0.005	0.154	<0.001
Final body weight, kg	98.25	99.42	98.55	99.12	1.49	0.396	0.680
Late finishing (day 77–94)							
ADG, kg	1.02	1.04	1.02	1.05	0.04	0.505	0.411
ADFI, kg	3.24	3.34	3.34	3.23	0.09	0.297	0.268
G:F	0.32	0.31	0.30	0.32	0.01	0.719	0.026
Final body weight, kg	116.34	118.18	116.83	117.68	1.51	0.218	0.567
Overall (day 1–94)							
ADG, kg	0.95	0.97	0.95	0.97	0.01	0.223	0.315
ADFI, kg	2.50	2.57	2.58	2.49	0.04	0.167	0.067
G:F	0.38	0.38	0.37	0.39	0.003	0.526	<0.001

[1]Each least squares mean represents 10 observations.
[2]Because the interaction between source of DDGS and diet form was not significant for any response variables ($P > 0.10$) only main effects of source of DDGS and diet form are shown.
[3]ADG, average daily gain; ADFI, average daily feed intake; G:F, gain to feed ratio.

Table 8. Carcass characteristics of pigs fed experimental diets containing cold-fermented or conventional distillers dried grains with solubles (DDGS)[1,2]

Item	Source of DDGS		Diet form			P-value	
Diet form	Cold-fermented	Conventional	Meal	Pellet	Pooled SEM	DDGS	Diet form
Hot carcass weight, kg	86.49	84.96	84.58	86.86	0.98	0.250	0.091
Dressing percentage, %	77.12	76.86	76.79	77.19	0.28	0.510	0.339
10th rib back fat, cm	1.31	1.37	1.21	1.48	0.09	0.586	0.028
Longissimus muscle area, sq. cm	51.15	50.17	50.42	50.89	1.21	0.352	0.664
Fat-free lean[3], kg	49.44	48.98	49.67	48.75	0.54	0.142	0.723
Fat-free lean[4], %	57.69	57.14	57.93	56.90	0.63	0.371	0.111

[1]Each least squares mean represents 10 observations.
[2]Because the interaction between source of DDGS and diet form was not significant for any response variables ($P > 0.10$) only main effects of source of DDGS and diet form are shown.
[3]Calculated from NPPC (1999): pounds fat-free lean = 8.588 – 21.896 × 10th rib back fat (in.) + 0.465 × hot carcass weight (lbs.) + 3.005 × *Longissimus* muscle area (sq. in.).
[4]Fat-free lean, % = (Fat-free lean / hot carcass weight) × 100 = % fat-free lean.

observation is in agreement with results of numerous previous experiments (Stein and Shurson, 2009; Cromwell et al., 2011), but it has also been reported that inclusion of DDGS may reduce growth performance of pigs (Whitney et al., 2006; Kim et al., 2012; Graham et al., 2014). The reason differences in growth performance of pigs have been reported among experiments in which DDGS was included in diets for growing-finishing pigs may be that differences in AA digestibility among different sources of DDGS have been reported (Stein et al., 2006; Pahm et al., 2008). Because cold-fermented DDGS had a greater digestibility of AA including Lys than conventional DDGS, inclusion of crystalline Lys was reduced in diets containing cold-fermented DDGS compared with conventional DDGS. The observation that this did not reduce growth performance or carcass characteristics of pigs indicated that the values used in diet formulations were accurate. The implication of this observation is that the cost of formulating diets is reduced if the two sources of DDGS have the same price and cold-fermented DDGS is used instead of conventional DDGS because less crystalline Lys is needed in diets containing cold-fermented DDGS.

The observation that the reduced ME that was determined in cold-fermented DDGS compared with conventional DDGS (Rodriguez et al., 2020) did not result in a reduced G:F for the overall nursery period or for the growing-finishing period indicates that the reduction in ME that was measured for cold-fermented DDGS is not big enough to have a measurable impact on G:F if the inclusion rate of DDGS in diets is 30% or less. However, as indicated above, if the DM in the conventional DDGS had been similar to the DM in cold-fermented DDGS, it is possible different values for G:F would have been calculated.

The improved G:F of pigs fed pelleted diets compared with pigs fed meal diets during the nursery phases, as well as the growing-finishing phases is in agreement with previous data (Steidinger et al., 2000; Rojas and Stein, 2016; Overholt et al., 2016). The increase in G:F that was observed in the growing-finishing period (approximately 5%) may be a result of increased ileal digestibility of starch and AA and therefore increased total tract digestibility of energy by pigs fed pelleted diets compared with pigs fed diets in meal form (Rojas et al., 2016). Thus, pelleting of DDGS-containing diets appears to be an effective way of increasing ME of the diets and thereby improving G:F. The positive effect of pelleting on G:F is also in agreement with results of a recent review that indicated that on average, pelleting increases G:F by 5.8% in growing-finishing pigs (Lancheros et al., 2020).

Inclusion of conventional DDGS in diets for weanling pigs has been reported from a limited number of experiments, and it has been concluded that 15% to 30% DDGS may be used in diets for weanling pigs without reducing growth performance (Whitney and Shurson, 2004; Linneen et al., 2006). Results of this experiment demonstrate that 15% low-oil DDGS from day 8 to 21 and 30% low-oil DDGS during the remaining nursery period does not compromise pig growth performance compared with pigs fed diets containing conventional DDGS, which indicates that pig responses to low-oil DDGS are not different from that of pigs fed conventional DDGS. We are not aware of previous data for weanling pigs fed diets containing low-oil DDGS, but the current results indicate that reducing the oil in DDGS does not have a negative impact on growth performance of weanling pigs.

Carcass characteristics

The observation that there were no differences between pigs fed low-oil cold-fermented DDGS and pigs fed conventional DDGS for HCW, dressing percentage, 10th rib back fat, or lean percentage indicates that under the conditions of this experiment, source of DDGS had no impact on carcass measurements. Pigs fed diets containing DDGS with 5.4% oil did not have carcass quality measurements that were different from pigs fed diets containing DDGS with 9.6% oil (Graham et al., 2014). The present results are, therefore, in agreement with previous data and indicate that within the ranges of oil in DDGS used in the present experiment and in the experiment by Graham et al. (2014), HCW, dressing percentage, and 10th rib back fat are not influenced by the concentration of oil in DDGS.

The observation that back fat was increased and HCW tended to increase in pigs fed pelleted diets compared with pigs fed meal diets is in agreement with previous data (Overholt et al., 2016). The increase in fat deposition is likely a result of increased ME and digestibility of energy, fat, and starch in pelleted diets compared with meal diets (Xing et al., 2004; Rojas et al., 2016; Lancheros et al., 2020). The observation that there was no difference in the amount of fat-free lean that was deposited between pigs fed pelleted and meal diets indicated that protein synthesis was not different between pigs fed meal diets and pelleted diets. It therefore appears that pelleting did not result in overheating because overheating may reduce availability of Lys and possibly other AA, and thereby reduce protein synthesis.

Conclusion

Use of cold-fermented or conventional DDGS in diets fed to pigs from 1 wk post-weaning and until market did not affect growth performance or carcass characteristics. However, pigs fed diets in a pelleted form had greater G:F than pigs fed diets in a meal form during the nursery period as well as the growing-finishing period. In addition, pigs fed pelleted diets had greater back fat than pigs fed diets in a meal form.

Acknowledgment

The financial support from POET Nutrition Inc., Sioux Falls, SD, is greatly appreciated.

Conflict of interest statement

The authors declare no real or perceived conflicts of interest.

Literature Cited

AOAC Int. 2007. *Official methods of analysis of AOAC int*. 18th ed. Rev. 2nd ed. Gaithersburg (MD): AOAC Int.

Cromwell, G. L., M. J. Azain, O. Adeola, S. K. Baidoo, S. D. Carter, T. D. Crenshaw, S. W. Kim, D. C. Mahan, P. S. Miller, and M. C. Shannon; North Central Coordinating Committee on Swine Nutrition. 2011. Corn distillers dried grains with solubles in diets for growing-finishing pigs: a cooperative study. *J. Anim. Sci.* **89**:2801–2811. doi:10.2527/jas.2010-3704

Graham, A. B., R. D. Goodband, M. D. Tokach, S. S. Dritz, J. M. DeRouchey, and S. Nitikanchana. 2014. The effects of medium-oil dried distillers grains with solubles on growth performance, carcass traits, and nutrient digestibility in growing-finishing pigs. *J. Anim. Sci.* **92**:604–611. doi:10.2527/jas.2013-6798

Kim, B. G., Y. Zhang, and H. H. Stein. 2012. 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. *J. Anim. Sci.* **90**:272–281. doi:10.2527/jas.2010-3777

Kim, B. G., D. Y. Kil, and H. H. Stein. 2013. In growing pigs, the true ileal and total tract digestibility of acid hydrolyzed ether extract in extracted corn oil is greater than in intact sources of corn or soybean oil. *J. Anim. Sci.* **91**:755–763. doi:10.2527/jas.2011–4777

Lancheros, J. P., C. D. Espinosa, and H. H. Stein. 2020. Effects of particle size reduction, pelleting, and extrusion on the nutritional value of ingredients and diets fed to pigs: a review. *Anim. Feed Sci. Technol.* **268**:114603. doi:10.1016/j.anifeedsci.2020.114603

Lee, S. A., C. Kong, O. Adeola, and B. G. Kim. 2016. Different coefficients and exponents for metabolic body weight in a model to estimate individual feed intake for growing-finishing pigs. *Asian-Australas. J. Anim. Sci.* **29**:1756–1760. doi:10.5713/ajas.16.0420

Lindemann, M. D., and B. G. Kim. 2007. Technical note: A model to estimate individual feed intake of swine in group feeding. *J. Anim. Sci.* **85**:972–975. doi:10.2527/jas.2006-412

Linneen, S. K., M. U. Steidiger, M. D. Tokach, J. M. DeRouchey, R. D. Goodband, S. S. Drits, and J. L. Nelssen. 2006. *Effects of dried distillers grain with solubles on nursery pig performance*. In: Kansas State Univ. Swine Day Report, Kansas State Univ., Manhattan.

NPPC. 1999. *Pork quality standards*. Des Moine (IA): National Pork Producers Council.

NRC. 2012. *Nutrient requirements of swine*. 11th rev. ed. Washington (DC): Natl. Acad. Press. doi:10.17226/13298

Overholt, M. F., J. E. Lowell, E. K. Arkfeld, I. M. Grossman, H. H. Stein, A. C. Dilger, and D. D. Boler. 2016. Effects of pelleting diets without or with distillers' dried grains with solubles on growth performance, carcass characteristics, and gastrointestinal weights of growing–finishing barrows and gilts. *J. Anim. Sci.* **94**:2172–2183. doi:10.2527/jas.2015-0202

Pahm, A. A., C. Pedersen, D. Hoehler, and H. H. Stein. 2008. Factors affecting the variability in ileal amino acid digestibility in corn distillers dried grains with solubles fed to growing pigs. *J. Anim. Sci.* **86**:2180–2189. doi:10.2527/jas.2008-0868

Rodriguez, D. A., S. A. Lee, and H. H. Stein. 2020. Digestibility of amino acids, but not fiber, fat, or energy, is greater in cold-fermented, low-oil distillers dried grains with solubles (DDGS) compared with conventional DDGS fed to growing pigs. *J. Anim. Sci.* **98**:skaa297. doi:10.1093/jas/skaa297

Rojas, O. J., and H. H. Stein. 2016. Use of feed technology to improve the nutritional value of feed ingredients. *Anim. Prod. Sci.* **56**:1312–1316. doi:10.1071/An15354

Rojas, O. J., and H. H. Stein. 2017. Processing of ingredients and diets and effects on nutritional value for pigs. *J. Anim. Sci. Biotechnol.* **8**:48. doi:10.1186/s40104-017-0177-1

Rojas, O. J., E. Vinyeta, and H. H. Stein. 2016. Effects of pelleting, extrusion, or extrusion and pelleting on energy and nutrient digestibility in diets containing different levels of fiber and fed to growing pigs. *J. Anim. Sci.* **94**:1951–1960. doi:10.2527/jas.2015-0137

Steidinger, M. U., R. D. Goodband, M. D. Tokach, S. S. Dritz, J. L. Nelssen, L. J. McKinney, B. S. Borg, and J. M. Campbell. 2000. Effects of pelleting and pellet conditioning temperatures on weanling pig performance. *J. Anim. Sci.* **78**:3014–3018. doi:10.2527/2000.78123014x

Stein, H. H., and G. C. Shurson. 2009. Board-invited review: the use and application of distillers dried grains with solubles in swine diets. *J. Anim. Sci.* **87**:1292–1303. doi:10.2527/jas.2008-1290

Stein, H. H., M. L. Gibson, C. Pedersen, and M. G. Boersma. 2006. Amino acid and energy digestibility in ten samples of distillers dried grain with solubles fed to growing pigs. *J. Anim. Sci.* **84**:853–860. doi:10.2527/2006.844853x

Whitney, M. H., and G. C. Shurson. 2004. Growth performance of nursery pigs fed diets containing increasing levels of corn distiller's dried grains with solubles originating from a modern Midwestern ethanol plant. *J. Anim. Sci.* **82**:122–128. doi:10.2527/2004.821122x

Whitney, M. H., G. C. Shurson, L. J. Johnston, D. M. Wulf, and B. C. Shanks. 2006. Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern Midwestern ethanol plant. *J. Anim. Sci.* **84**:3356–3363. doi:10.2527/jas.2006-099

Wu, F., L. J. Johnston, P. E. Urriola, and G. C. Shurson. 2016. Pork fat quality of pigs fed distillers dried grains with solubles with variable oil content and evaluation of iodine value prediction equations. *J. Anim. Sci.* **94**:1041–1052. doi:10.2527/jas.2015-9593

Xing, J. J., E. van Heugten, D. F. Lit, K. J. Touchette, J. A. Coalson, R. L. Odgaard, and J. Odle. 2004. Effects of emulsification, fat encapsulation, and pelleting on weanling pig performance and nutrient digestibility. *J. Anim. Sci.* **82**:2601–2609. doi:10.2527/2004.8292601x