

Evaluation of high-protein distillers dried grains on growth performance and carcass characteristics of growing-finishing pigs

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ABSTRACT: A total of 1,890 growing-finishing pigs (PIC; 359 × 1,050; initially 27.1 kg) were used in a 124-d growth trial to compare the effects of high-protein distillers dried grains (HPDDG; 39% crude protein [CP]) or conventional distillers dried grains with solubles (DDGS; 29% CP) on growth performance and carcass characteristics. Treatments were arranged in a 2 × 2 + 1 factorial with main effects of distillers dried grains source (conventional DDGS or HPDDG) and level (15% or 30%). A corn–soybean meal-based diet served as the control and allowed linear and quadratic level effects to be determined within each distillers dried grains (DDG) source. All diets were formulated on an equal standardized ileal digestible (SID) Lys-basis with diets containing HPDDG having less soybean meal than diets with conventional DDGS. Pens were assigned to treatments in a randomized complete block design with initial weight as the blocking factor. There were 27 pigs per pen and 14 pens per treatment. Overall, increasing conventional DDGS decreased (linear, $P < 0.04$) final body weight (BW), whereas increasing HPDDG

tended to decrease (linear, $P = 0.065$) final BW. The decreased final BW was a result of decreased (linear, $P < 0.01$) ADG in the grower phase of the study as either DDG source increased. However, there were no differences observed in the finisher phase or overall ADG between pigs fed either DDG source or either inclusion level. Pigs fed HPDDG had decreased ($P < 0.001$) ADFI and increased ($P < 0.001$) G:F compared with those fed conventional DDGS. For carcass traits, increasing either conventional DDGS or HPDDG decreased carcass yield and HCW (linear, $P < 0.02$); however, there were no differences between pigs fed HPDDG or conventional DDGS. Iodine value (IV) increased (linear, $P < 0.02$) with increasing DDG and was greater ($P < 0.001$) in pigs fed HPDDG than conventional DDGS. In summary, pigs fed HPDDG had no evidence of difference in overall ADG compared to pigs fed conventional DDGS, but had greater overall G:F. Carcass fat IV was also greater in pigs fed HPDDG compared with pigs fed conventional DDGS. These differences were probably due to the difference in oil content.

Key words: DDGS, growth, grow-finish pigs, high-protein distillers dried grains, iodine value

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INTRODUCTION

Distillers dried grains with solubles (DDGS) is a co-product of the ethanol industry that can be fed at up to 30% of the diet without negative effect for growing-finishing pigs (Stein and Shurson,

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2009). Conventional DDGS has lower concentration of starch, but the concentration of oil, acid detergent fiber (ADF), neutral detergent fiber (NDF), total dietary fiber, and amino acids are greater than corn (Stein and Shurson, 2009). Nonetheless, the apparent total tract digestibility of fiber and AAs in DDGS are slightly less than in corn. The higher concentration of oil in DDGS increases the carcass fat iodine value (IV) which reduces the firmness of pork fat (Stein and Shurson, 2009).

New technologies have been introduced by the ethanol industry to improve the efficiency of ethanol production, resulting in new types of distiller dried grain with different nutrient profiles. One of the new processing techniques removes fibrous corn components before fermentation which results in greater ethanol production and a high-protein distillers dried grains by-product (HPDDG) with approximately 40% CP and 10% oil (Rho et al., 2017). Recent research has shown this new HPDDG product has higher CP and digestibility of some nutrients (Espinosa and Stein, 2018), and digestible energy (DE; Rho et al., 2017) than conventional DDGS, which may be beneficial to growing-finishing pig performance. However, while several studies have evaluated the effect of older types of HPDDG on growing-finishing or nursery pig performance, limited research has been conducted with this new process for manufacturing HPDDG to confirm its effects on growth performance and carcass characteristics of growing-finishing pigs.

A challenge when using DDGS and HPDDG in diets for pigs is an excess dietary leucine concentration. This is due to a high level of leucine in corn protein, thus as the protein level increases in HPDDG, the leucine level increases as well. This needs to be considered because of the antagonism between different branched-chain amino acids (BCAA) that causes reduced growth performance (Cemin et al., 2019c). Cemin et al. (2019c) provide a basis for diet formulation to minimize BCAA antagonisms which was utilized in this study to account for the difference in BCAA profile between DDG sources and inclusion level. This equation predicted equal ADG across dietary treatments. Therefore, the objective of this study was to characterize the effects of this new HPDDG source on growth performance and carcass characteristics of 27–130-kg growing-finishing pigs when accounting for dietary BCAA levels.

MATERIALS AND METHODS

The Kansas State University Institutional Animal Care and Use Committee approved the

protocol used in this experiment. The study was conducted at a commercial research-finishing site in southwest Minnesota. The barn was naturally ventilated and double-curtain-sided. Each pen was equipped with a 5-hole stainless steel dry self-feeder and a bowl waterer for ad libitum access to feed and water.

Two groups of approximately 945 pigs (1,890 total pigs; PIC 359 × 1050; initially 27.1 ± 2.2 kg) were used in a 124-d growth trial. Pigs were housed in mixed sex pens with 27 pigs per pen and 14 pens per treatment (7 replications per group). Daily feed additions to each pen were accomplished and recorded using a robotic feeding system (FeedPro, Feedlogic Corp., Wilmar, MN). The treatments were structured as a randomized complete block design and arranged in a $2 \times 2 + 1$ factorial with main effects of DDG source (conventional DDGS and HPDDG) and level (15% or 30%). A corn-soybean meal-based diet without DDG served as the control. For diet formulation, nutrient and SID amino acid values for DDGS were derived from NRC (2012). For HPDDG, total AAs, dry matter, CP, ether extract, ash, NDF and ADF values were from Cemin et al. (2019b) and other nutrient values were derived from NRC (2012), and standardized ileal digestibility of AAs were derived from Rho et al. (2017). Conventional DDGS contained 29.0% CP, 9.2% oil, and assumed 0.48% SID Lys and 2,364 kcal/kg net energy (NE), whereas HPDDG contained 39.3% CP, 11.1% oil, and assumed 0.68% SID Lys and 2,685 kcal/kg NE. Conventional DDGS used in this study was made by Valero Aurora Ethanol Plant (Aurora, SD). High-protein DDG used in this study was made by ICM Biofuels (St Joseph, MO). Representative samples of each batch of corn, conventional DDGS, and HPDDG were collected, homogenized, and analyzed for dry matter (method 935.29; AOAC Int., 2019), crude protein (method 990.03; AOAC Int., 2019), Ca (method 6.3; Kovar, 2003), P (method 6.3; Kovar, 2003), neutral detergent fiber (ANKOM Technology, 2005), and ether extract (ANKOM Technology, 2004) at Ward Laboratories, Inc. (Kearney, NE; Table 1). Amino acid analysis was conducted with cation-exchange chromatography coupled with post-column ninhydrin derivatization and quantitation (AOAC Int., 2019) at the Experiment Station Chemical Laboratories of the University of Missouri (Columbia, MO). The multiple mycotoxin assay conducted at North Dakota State University Veterinary Diagnostic Laboratory was based on an Agilent Technologies (Santa Clara, CA) method for mycotoxin in corn using ultra high-pressure

Table 1. Chemical analysis of ingredients (as-fed basis)^a

Item	Conventional		
	Corn	DDGS	HPDDG
Proximate analysis, %			
Dry matter	86.53	90.15	92.62
Crude protein	6.73	29.03	39.17
Calcium	0.10	0.12	0.17
Phosphorus	0.33	1.08	0.73
Neutral detergent fiber	6.83	29.87	30.60
Ether extract	3.20	8.03	10.27
Indispensable amino acids, %			
Arginine	0.26	1.33	1.77
Histidine	0.18	0.84	1.08
Isoleucine	0.22	1.17	1.64
Leucine	0.69	3.34	4.69
Lysine	0.22	1.03	1.48
Methionine	0.12	0.51	0.82
Phenylalanine	0.29	1.50	2.08
Threonine	0.22	1.13	1.51
Tryptophan	0.05	0.22	0.33
Valine	0.29	1.48	2.06
Dispensable amino acids, %			
Alanine	0.43	1.90	2.73
Aspartic Acid	0.42	1.79	2.63
Cysteine	0.14	0.58	0.76
Glutamic Acid	1.06	3.53	5.79
Glycine	0.24	1.18	1.51
Proline	0.52	2.21	3.01
Serine	0.27	1.27	1.69
Taurine	0.10	0.07	0.08
Tyrosine	0.13	1.04	1.46

DDGS = distillers dried grains with solubles. HPDDG = high protein distillers dried grains.

^aRepresentative samples of each batch of each ingredient was collected, homogenized, and submitted for proximate analysis (Ward Laboratories, Inc., Kearney, NE) and amino acid analysis (Experiment Station Chemical Laboratories, University of Missouri, Columbia, MO). The result shown was the average of three batches of ingredients used.

liquid chromatography and tandem mass spectrometric detection (UHPLC/MS/MS) with modifications (Varga et al., 2013; Table 2). The detail of this analysis can be found in Rao et al. (2020). The analyzed total AA profile of this experiment was similar to the values we used for diet formulation (Cemin et al. 2019b) in this experiment.

Dietary treatments were fed in four phases based on body weight. All diets were formulated on an equal SID Lys-basis with diets containing HPDDG having less soybean meal (SBM) than diets with conventional DDGS and the control diet (Tables 3 and 4). By design, NE was not balanced between treatments for each phase. Thus, differences in feed efficiency would reflect differences in energy value of the dietary treatments. In addition,

Table 2. Dietary mycotoxin concentrations (as-fed basis, ug/kg)^a

Item	Conventional DDGS		
	Corn	DDGS	HPDDG
Aflatoxin B1	< 20	< 20	< 20
Aflatoxin B2	< 20	< 20	< 20
Aflatoxin G1	< 20	< 20	< 20
Aflatoxin G2	< 20	< 20	< 20
Fumonisin B1	< 200	240	9,234
Fumonisin B2	< 200	< 200	2,950
HT-2 toxin	< 200	< 200	< 200
T-2 Toxin	< 20	< 20	< 20
Ochratoxin	< 20	< 20	< 20
Sterigmatocystin	< 20	< 20	< 20
Zearalenone	< 100	122.3	305.7
Vomitoxin	418.3	897.7	868.3

DDGS = distillers dried grains with solubles. HPDDG = high protein distillers dried grains.

^aRepresentative samples of each ingredient were collected for each batch. The result was reported as the average of three batches. Diet mycotoxin concentration was analyzed at North Dakota State University Veterinary Diagnostic Laboratory (Fargo, ND) by LC/MS/MS assay.

dietary BCAA ratios were adjusted based on the equation of Cemin et al. (2019a) to account for the excess dietary leucine in the conventional DDGS and HPDDG. The formulated dietary SID Ile:Lys and Val:Lys ratios increased as the level of conventional DDGS or HPDDG increased. Because of the greater Ile, Leu and Val concentration in HPDDG than conventional DDGS, diets with HPDDG had greater BCAA:Lys ratios compared to conventional DDGS at the same dietary inclusion (15% or 30%). This was also a result of the greater lysine level of HPDDG that resulted in lower SBM inclusion level compared to diet with DDGS (Tables 3 and 4).

Pigs were weighed approximately every 14 days from d 0 to 124 of the trial to determine ADG, ADFI, and G:F. Caloric efficiency (CE) has been used to estimate the energy of an ingredient by comparing it to a known ingredient, such as corn (Cemin et al., 2020). It was calculated by dividing net energy intake by weight gain. For our experiment, CE was calculated for grower, finisher, and overall phase based on the energy values of ingredients used for diet formulation to determine the energy estimate of HPDDG. By increasing the inclusion level of the HPDDG in diet, CE should remain the same if the initial energy estimate of HPDDG is accurate. However, if CE linearly decreases as the level of HPDDG increases, it suggests that HPDDG has greater energy value than what was used in the initial diet formulation.

On d 103, the three heaviest pigs in each pen were selected and marketed as per the standard

Table 3. Composition of phase 1 and 2 diets (as-fed basis)^{a,b}

Items	Phase 1					Phase 2				
	Control	Conventional DDGS		HPDDG		Control	Conventional DDGS		HPDDG	
		15%	30%	15%	30%		15%	30%	15%	30%
Ingredients, %										
Corn	74.30	61.92	50.42	63.24	52.93	80.26	69.06	57.56	70.31	60.08
Soybean meal	22.52	20.14	16.82	18.94	14.42	16.91	13.27	9.94	12.07	7.54
Corn DDGS	–	15.00	30.00	–	–	–	15.00	30.00	–	–
HPDDG	–	–	–	15.00	30.00	–	–	–	15.00	30.00
Limestone, ground	1.00	1.13	1.23	1.10	1.20	0.95	1.05	1.15	1.05	1.13
Monocalcium phosphate	0.65	0.40	0.15	0.40	0.15	0.50	0.25	0.00	0.30	0.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
L-Lysine-HCl	0.48	0.50	0.55	0.50	0.55	0.44	0.50	0.55	0.50	0.55
DL-Methionine	0.14	0.08	0.03	0.02	0.00	0.10	0.05	0.00	0.00	0.00
L-Threonine	0.23	0.19	0.15	0.17	0.11	0.19	0.17	0.13	0.14	0.08
L-Tryptophan	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04
L-Valine	0.11	0.08	0.08	0.07	0.08	0.09	0.09	0.10	0.06	0.07
Vitamin and trace mineral premix ^c	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Phytase ^d	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Calculated analysis										
Standardized ileal digestible (SID) amino acids, %										
Lysine	1.13	1.13	1.13	1.13	1.13	0.96	0.96	0.96	0.96	0.96
Isoleucine:lysine	55	59	62	63	70	55	57	60	62	69
Leucine:lysine	113	134	153	151	186	119	141	163	161	203
Methionine:lysine	34	32	30	29	33	33	31	30	29	36
Methionine and cysteine:lysine	56	56	56	56	65	56	56	57	58	70
Threonine:lysine	65	65	65	65	65	65	65	65	65	65
Tryptophan:lysine	19.0	18.8	19.1	18.8	19.1	18.8	18.9	18.8	18.9	18.7
Valine:lysine	70	74	79	78	88	70	76	82	78	90
Lysine:net energy, g/Mcal	4.42	4.49	4.55	4.39	4.35	3.69	3.74	3.79	3.66	3.63
Net energy, kcal/kg	2,552	2,510	2,477	2,567	2,589	2,594	2,563	2,530	2,616	2,642
STTD P, %	0.38	0.38	0.38	0.38	0.38	0.34	0.34	0.34	0.34	0.33
Proximate analysis, % ^e										
Dry matter	87.02	88.69	88.63	88.49	89.22	88.09	88.06	89.84	88.31	89.35
Crude protein	14.9	17.2	19.7	18.1	22.0	16.1	16.9	17.5	17.7	20.4
Calcium	0.60	0.53	0.53	0.52	0.48	0.58	0.50	0.53	0.48	0.45
Phosphorus	0.41	0.44	0.46	0.40	0.41	0.42	0.41	0.44	0.39	0.37
Neutral detergent fiber	7.2	10.4	13.8	9.2	14.2	7.6	10.6	12.8	9.7	13.8
Ether extract	2.9	3.9	4.5	4.3	5.6	3.1	3.9	4.9	4.4	5.4

DDGS = distillers dried grains with solubles. HPDDG = high protein distillers dried grains. STTD = standardized total tract digestible phosphorus.

^aPhases 1 and 2 were fed from 27 to 50 and 50 to 73 kg, respectively.

^bEquation used for ADG (g/d) prediction (Cemin et al., 2019a): $-985.94 + (15.2499 \times \text{average BW [kg]}) - (0.08885 \times \text{average BW} \times \text{average BW}) + (1.063 \times \text{Leu:Lys}) + (20.2659 \times \text{Ile:Lys}) - (0.1479 \times \text{Ile:Lys} \times \text{Ile:Lys}) + (9.2243 \times (\text{Ile+Val}):Leu) - (0.03321 \times (\text{Ile+Val}):Leu \times (\text{Ile+Val}):Leu) - (0.4413 \times \text{Ile:Trp})$.

^cProvided per kg of premix: 3,527,360 IU vitamin A; 881,840 IU vitamin D; 17,637 IU vitamin E; 1,764 mg vitamin K; 15.4 mg vitamin B12; 33,069 mg niacin; 11,023 mg pantothenic acid; 3,307 mg riboflavin; 74 g Zn from zinc sulfate; 74 g Fe from iron sulfate; 22 g Mn from manganese oxide; 11 g Cu from copper sulfate; 0.22 g I from calcium iodate; and 0.20 g Se from sodium selenite.

^dOptiphos 2000 (Huvepharma Inc., Peachtree City, GA) provided 871 units of phytase/kg of diet with an assumed release of 0.11% STTD P.

^eAt least six representative samples of each diet were collected for each treatment, homogenized, and submitted for proximate analysis (Ward Laboratories, Inc., Kearney, NE).

farm marketing protocol. These pigs were included in the growth performance data but not in carcass data. On the last day of the trial, final pen weights were taken, and the remaining pigs were tattooed

with a pen identification number and transported to a USDA-inspected packing plant (JBS Swift, Worthington, MN) for carcass data collection. Carcass measurements included hot carcass weight

Table 4. Composition of phase 3 and 4 diets (as-fed basis)^{a,b}

Items	Phase 3					Phase 4				
	Control	Conventional DDGS		HPDDG		Control	Conventional DDGS		HPDDG	
		15%	30%	15%	30%		15%	30%	15%	30%
Ingredients, %										
Corn	84.75	73.32	61.78	74.52	64.28	86.15	75.37	63.83	76.64	66.33
Soybean meal	12.52	9.19	5.87	8.00	3.47	11.29	7.17	3.85	5.97	1.45
Corn DDGS	–	15.00	30.00	–	–	–	15.00	30.00	–	–
HPDDG	–	–	–	15.00	30.00	–	–	–	15.00	30.00
Limestone, ground	0.93	1.03	1.13	1.03	1.10	0.90	1.00	1.10	1.00	1.10
Monocalcium phosphate	0.55	0.25	0.00	0.30	0.00	0.50	0.25	0.00	0.25	0.00
Salt	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
L-Lysine-HCl	0.40	0.45	0.50	0.45	0.50	0.38	0.45	0.50	0.45	0.50
DL-Methionine	0.06	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
L-Threonine	0.16	0.13	0.09	0.11	0.05	0.15	0.12	0.09	0.10	0.04
L-Tryptophan	0.05	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.04	0.04
L-Valine	0.06	0.07	0.06	0.04	0.04	0.04	0.07	0.06	0.03	0.02
Vitamin and trace mineral premix ^c	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Phytase ^d	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Calculated analysis										
Standardized ileal digestible (SID) amino acids, %										
Lysine	0.82	0.82	0.82	0.82	0.82	0.77	0.77	0.77	0.77	0.77
Isoleucine:lysine	55	58	61	63	72	55	57	60	63	72
Leucine:lysine	127	153	179	176	225	132	157	185	182	234
Methionine:lysine	32	29	33	32	39	31	29	33	33	41
Methionine and cysteine:lysine	56	56	62	63	78	56	57	64	65	80
Threonine:lysine	65	65	65	65	65	65	65	65	65	65
Tryptophan:lysine	19.1	19.0	18.8	18.9	18.7	18.9	18.8	18.6	18.8	18.6
Valine:lysine	70	77	83	80	94	70	78	84	80	93
Lysine:net energy, g/Mcal	3.12	3.16	3.20	3.09	3.07	2.92	2.95	2.99	2.89	2.86
Net energy, kcal/kg	2,622	2,589	2,556	2,644	2,669	2,631	2,605	2,572	2,660	2,682
STTD P, %	0.33	0.33	0.33	0.33	0.32	0.32	0.32	0.32	0.32	0.32
Proximate analysis, % ^e										
Dry matter	86.95	87.91	88.25	88.28	88.53	87.94	88.63	89.49	88.07	88.87
Crude protein	12.0	13.2	15.7	15.1	18.3	12.5	14.2	14.6	15.1	17.2
Calcium	0.57	0.58	0.45	0.51	0.58	0.55	0.49	0.45	0.55	0.50
Phosphorus	0.37	0.40	0.43	0.36	0.35	0.40	0.40	0.41	0.36	0.32
Neutral detergent fiber	7.8	9.0	13.3	10.5	12.7	7.7	10.9	12.1	10.5	12.6
Ether extract	3.5	3.9	4.8	4.5	5.5	3.5	4.4	4.7	4.7	5.4

DDGS = distillers dried grains with solubles. HPDDG = high protein distillers dried grains. STTD = standardized total tract digestible phosphorus.

^aPhases 3 and 4 were fed from 73 to 100 and 100 kg to marketing, respectively.

^bEquation used for ADG (g/d) prediction (Cemin et al., 2019a): $-985.94 + (15.2499 \times \text{average BW (kg)}) - (0.08885 \times \text{average BW} \times \text{average BW}) + (1.063 \times \text{Leu:Lys}) + (20.2659 \times \text{Ile:Lys}) - (0.1479 \times \text{Ile:Lys} \times \text{Ile:Lys}) + (9.2243 \times (\text{Ile+Val}):Leu) - (0.03321 \times (\text{Ile+Val}):Leu \times (\text{Ile+Val}):Leu) - (0.4413 \times \text{Ile:Trp})$.

^cProvided per kg of premix: 3,527,360 IU vitamin A; 881,840 IU vitamin D; 17,637 IU vitamin E; 1,764 mg vitamin K; 15.4 mg vitamin B12; 33,069 mg niacin; 11,023 mg pantothenic acid; 3,307 mg riboflavin; 74 g Zn from zinc sulfate; 74 g Fe from iron sulfate; 22 g Mn from manganese oxide; 11 g Cu from copper sulfate; 0.22 g I from calcium iodate; and 0.20 g Se from sodium selenite.

^dOptiphos 2000 (Huvepharma Inc. Peachtree City, GA) provided 871 units of phytase/kg of diet with an assumed release of 0.11% STTD P.

^eAt least six representative samples of each diet were collected for each treatment, homogenized, and submitted for proximate analysis (Ward Laboratories, Inc., Kearney, NE).

(HCW), loin depth, backfat, percentage lean, and fat iodine value (IV). Fat samples for IV analysis were collected from two pigs per pen at the shoulder of the carcasses (all three fat layers) from the first

group of pigs. The fat samples were analyzed using Fourier transform near infrared (FT-NIR) on a Bruker MATRIX-I FT-NIR spectrometer (Billerica, MA). Percentage lean was calculated

from a plant proprietary equation. Carcass yield was calculated by taking the pen average HCW divided by the pen average final live weight obtained at the farm.

Statistical Analysis

Data were analyzed as a randomized complete block design for two-way ANOVA using the lmer function from the lme4 package in R program (R Core Team, 2019) with pen considered the experimental unit, initial BW and group as blocking factor, and treatment as fixed effect. Phases 1 and 2 were combined to represent the grower phase, while phases 3 and 4 were combined and referred to as the finisher phase for growth performance analysis. Predetermined contrasts were used to evaluate the main effects and interactive effects of DDG source \times level among treatments. Preplanned contrasts were also used to examine the linear and quadratic responses due to increasing DDG addition within DDG source using the control diet (as 0% inclusion level) and the 15% and 30% diets. All results were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

Based on the literature from 2007 to 2018 and NRC (2012), there are several types of HPDDG with or without solubles (Widmer et al., 2007, 2008; Kim et al., 2009; Jacela et al., 2010; Almeida and Stein, 2012; Gutierrez et al., 2014; Petersen et al., 2014; Adeola and Ragland, 2016; Rho et al., 2017; Espinosa and Stein, 2018; Yang et al., 2018). According to the nutrient analysis, these HPDDG sources have similar AA to CP ratios, but CP, Ca, P, oil, and NDF content varies. The major difference between the other HPDDG sources and the HPDDG used in the current study is that before fermentation of the corn starch to ethanol the fiber component of the corn kernel is removed (M. Wilken, personal communication). This processing method reduces the ADF content of HPDDG with NDF remaining relatively unchanged as a percentage of the product compared to conventional DDGS. This results in a HPDDG source that has a greater oil content (Rho et al., 2017; Espinosa and Stein, 2018; Yang et al., 2018) compared to other HPDDG sources on the market. The variation in nutrient composition of HPDDG can be a result of differences in processing methods, the type of yeast used for fermentation, the complexity of dry-grind process, and the amount of solubles added back (Liu, 2011).

The HPDDG used in this trial had a greater crude protein (39.2% vs. 29.0%) and oil content (10.3% vs. 8.0%) compared to the conventional DDGS. Furthermore, this HPDDG had higher oil content (10.3% vs. 3.54%), Ca (0.17% vs. 0.02%), P (0.73% vs. 0.36%), and lower CP (39.2% vs. 45.4%) compared to the values listed for HPDDG in NRC (2012), therefore caution should be used when applying nutrient values from NRC (2012) for HPDDG because of the many manufacturing processes. The total P content was lower in HPDDG compared to conventional DDGS (0.73% vs. 1.08%) because HPDDG did not contain the soluble portion of distillers dried grain production. The ratios of AAs to CP were similar between corn, HPDDG, and conventional DDGS, however the digestibility of AAs may be lower for DDGS and HPDDG compared to corn because of the DDG production processes (Stein and Shurson, 2009). Rho et al. (2017) compared similar HPDDG as in the current experiment with conventional DDGS and found that DE and SID concentrations of indispensable AAs and CP were greater compared to conventional DDGS. Espinosa et al. (2018) observed that similar HPDDG used in growing-finishing pigs had greater ($P < 0.05$) DE and ME, SID Leu, Lys, Met, Phe, and Glu compared to conventional DDGS.

Three batches of corn, HPDDG, and conventional DDGS were used and analyzed for mycotoxins (North Dakota State University Veterinary Diagnostic Laboratory, Fargo, ND). Fumonisin concentrations ranged from approximately 8 to 15 mg/kg in HPDDG and 0.2–0.3 mg/kg in conventional DDGS (Table 2). Vomitoxin concentrations were similar between DDG sources which ranged from approximately 0.8 to 1.0 mg/kg. Based on the inclusion of the DDG sources, these mycotoxin levels would not be considered to negatively affect growing-finishing pig health and performance (Ensely and Radke, 2019; Rao et al., 2020). Chemical analysis (Tables 3 and 4) of treatment diets for dry matter, crude protein, Ca, P, neutral detergent fiber, and ether extract were within formulated ranges.

In the grower phase (day 0–55), increasing either DDG source decreased (linear, $P < 0.001$) ADG (Table 5). In the finisher phase (day 55–124), there was a tendency for pigs fed 15% conventional DDGS had reduced (quadratic, $P = 0.065$) ADG compared to those fed 0% or 30%. There was no evidence of differences observed in overall ADG. Increasing conventional DDGS decreased (linear, $P = 0.039$) final body weight (BW), whereas increasing HPDDG tended to decrease (linear, $P = 0.065$) final

Table 5. The effects of DDG source and level on grow-finish pig growth performance, and carcass characteristics^a

Item	Probability, P =										
	Control (0%)	Conventional DDGS		HPDDG		SEM	Source	Conventional DDGS		HPDDG	
		15%	30%	15%	30%			Linear	Quadratic	Linear	Quadratic
BW, kg											
Initial	27.1	27.1	27.1	27.1	27.1	0.61	0.853	0.801	0.955	0.948	0.940
Ending	130.0	127.3	127.8	129.0	128.0	2.29	0.199	0.039	0.098	0.065	0.974
Grower phase^b											
ADG, g	893	879	862	875	852	15.8	0.249	< 0.001	0.831	< 0.001	0.772
ADFI, g ^c	1,870	1,840	1,828	1,825	1,721	40.7	0.002	0.121	0.696	< 0.001	0.197
G:F, g/kg ^c	479	479	472	480	497	4.00	< 0.001	0.180	0.380	< 0.001	0.081
CE, kcal/kg	5,395	5,317	5,322	5,420	5,300	44.7	0.271	0.164	0.353	0.071	0.109
Finisher phase^d											
ADG, g	855	833	864	860	870	20.3	0.166	0.571	0.065	0.368	0.858
ADFI, g ^c	2,609	2,604	2,644	2,555	2,510	54.8	< 0.001	0.256	0.399	0.002	0.862
G:F, g/kg	328	321	327	336	347	4.67	< 0.001	0.868	0.160	0.001	0.840
CE, kcal/kg	8,040	8,136	7,890	7,937	7,743	107.6	0.064	0.250	0.132	0.026	0.689
Overall											
ADG, g	876	857	865	870	863	6.8	0.375	0.252	0.101	0.194	0.950
ADFI, g ^c	2,262	2,243	2,259	2,212	2,139	30	< 0.001	0.902	0.422	< 0.001	0.603
G:F, g/kg	388	382	384	394	404	4.15	< 0.001	0.371	0.393	< 0.001	0.592
CE, kcal/kg	6,747	6,758	6,655	6,699	6,586	71.6	0.225	0.220	0.380	0.033	0.606
Carcass characteristics											
HCW, kg	94.9	92.5	92.1	94.0	92.0	1.50	0.189	< 0.001	0.127	< 0.001	0.443
Carcass yield, %	73.1	72.6	72.1	72.9	71.9	0.324	0.920	0.019	0.849	0.005	0.231
Backfat depth, mm ^f	15.9	15.5	15.9	15.8	15.6	0.28	0.978	0.954	0.241	0.421	0.699
Loin depth, mm ^f	67.0	67.0	66.9	67.3	66.7	0.46	0.828	0.847	0.947	0.684	0.426
Lean, % ^f	57.2	57.5	57.2	57.3	57.4	0.181	0.978	0.901	0.272	0.552	0.909
Iodine value ^e , g/100g	64.8	69.0	73.7	72.9	80.0	0.76	< 0.001	< 0.001	0.818	< 0.001	0.546

DDGS = distillers dried grains with solubles. HPDDG = high protein distillers dried grains. BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. G:F = gain-to-feed ratio. CE = caloric efficiency (the amount of energy consumed per kg of BW gain). HCW = hot carcass weight.

^aA total of 1,890 pigs (initially 27.1 kg) were used in two groups with 27 pigs per pen and 14 replicates per treatment.

^bGrower phase was from d 0 to 55 in group 1 and from d 0 to 55 in group 2.

^cInteractive effect, source × level $P < 0.05$.

^dFinisher phase was from d 55 to 113 in group 1 and from d 55 to 124 in group 2.

^eInteractive effect, source × level $0.05 < P \leq 0.10$.

^fAdjusted using HCW as covariate.

BW. This is likely due to changes in ADG during the grower phase. Increasing HPDDG decreased (linear, $P \leq 0.002$) ADFI and improved (linear, $P \leq 0.002$) G:F in both phases and the overall period, whereas there was no change in ADFI or G:F among pigs fed conventional DDGS.

Conventional DDGS and HPDDG have greater SID Ile:Lys, Leu:Lys, and Val:Lys ratios and lower Lys:CP ratio compared to SBM. Therefore, including these ethanol co-products and reducing SBM inclusion to achieve the same SID Lys would increase the SID Ile:Lys, Leu:Lys, and Val:Lys ratios in the diet. Isoleucine, Leu, and Val are BCAA that have similar molecular structure and share several catabolism pathways (Harper et al., 1984). All BCAAs

can be catabolized by branched-chain aminotransferase and branched-chain α -keto acid dehydrogenase complex. Excess of either of the BCAA in diets upregulate the enzymatic activity which would increase the catabolism of all BCAA. This antagonistic effect reduces the growth performance of growing-finishing pigs (Cemin et al., 2019c). Therefore, we formulated our diets based on the equation developed by Cemin et al. (2019a) to predict equal ADG by adjusting dietary SID Ile:Lys, Leu:Lys, Trp:Lys, and Val:Lys ratios accordingly.

Based on the improved G:F and decreased ADFI in pigs fed HPDDG, its energy content appears to be greater than the conventional DDGS used in this study. The improvement in G:F of pigs fed increasing

HPDDG compared to conventional DDGS may be due to the higher oil content or improved nutrient digestibility in HPDDG. By calculating the caloric efficiency (CE) of diets using procedures of Cemin et al. (2019b), CE was linearly improved ($P = 0.033$) as HPDDG increased. Therefore, we suspected that the initial net energy (NE) of HPDDG was underestimated. For CE of HPDDG diets to be identical to the control diet, the NE of HPDDG would have to be 103.4% of the energy of corn, which was greater than the value (97.3%; Cemin et al., 2019b) used for diet formulation.

Yang et al. (2018) fed 0% to 30% HPDDG from similar processing method as that used in this study to nursery pigs and found that increasing HPDDG linearly decreased ($P < 0.01$) ADG, ADFI, and G:F. Cemin et al. (2019b) observed decreases in ADG in pigs from 12 to 22 kg. In the current experiment, we also observed a linear decrease in ADG as either DDG source increased in the grower phase similar to Yang et al. (2018) and Cemin (2019b). Applying dietary AA values of Yang et al. (2018) to the equation of Cemin et al. (2019a) results in a predicted reduction in ADG as the inclusion of HPDDG increases. This is because of the high SID Leu:Lys ratio and relatively low Val:Leu and Ile:Leu ratios. In our experiment, we accounted for differences in BCAA ratios across treatments to estimate similar ADG. Because of the reduced in ADFI observed by Yang et al. (2018), Cemin et al. (2019b), and our experiment, initial palatability might be a factor. In addition, the high fiber content in diets containing HPDDG may cause reduced feed intake because of the increased bulk volume of feed in the intestine (Nyachoti et al., 2004; Avelar et al., 2010).

For carcass characteristics, increasing either conventional DDGS or HPDDG decreased carcass yield and HCW (linear, $P < 0.02$). This was expected as conventional DDGS and HPDDG increase the dietary crude fiber content of the diets which increased gut fill and intestine mass of pigs (Stein and Shurson, 2009). Because intestine weight is not included in carcass weight, the carcass yield and HCW were reduced. There were no differences among dietary treatments in back fat, loin depth, or percentage lean.

Carcass fat iodine value (IV) is an important measure for carcass fat softness. High IV results in low belly fat firmness which is undesirable (Stein and Shurson, 2009). Carcass fat IV was greater ($P < 0.001$) in pigs fed HPDDG than conventional DDGS, and IV increased (linear, $P < 0.02$) with increasing inclusion level of either DDG source. Similar to the improvements in G:F, the change

in IV between pigs fed HPDDG and conventional DDGS was most likely due to the differences in oil content.

In summary, these data suggest that feeding pigs up to 30% HPDDG may have economic advantages because of its amino acid profile and improved G:F compared with those fed conventional DDGS, while maintaining similar ADG and G:F to pigs fed a corn–soybean meal based diet. However, caution must be used with the type of HPDDG used because of the different nutrient profiles, especially AA profile, oil, and energy content. Accurate AA profile allows adjustment of SID Ile:Lys, Leu:Lys, Trp:Lys, and Val:Lys to avoid BCAA imbalance that may cause reduced growth performance. Also, a potential concern with many DDG sources is the oil content which if high enough, leads to a greater unsaturated fat content in the carcass, which would increase carcass fat IV and reduce carcass fat firmness.

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