

# Growth performance of nursery pigs fed diets containing increasing levels of a novel high-protein corn distillers dried grains with solubles<sup>1</sup>

Zhaohui Yang,\* Pedro E. Urriola,\*<sup>⊙</sup> Adrienne M. Hilbrands,<sup>†</sup> Lee J. Johnston,<sup>†</sup> and Gerald C. Shurson\*<sup>2</sup>

\*Department of Animal Science, University of Minnesota, St. Paul, MN 55108; and <sup>†</sup>West Central Research and Outreach Center, University of Minnesota, Morris, MN 56267

**ABSTRACT:** The objective of this study was to use the recently determined ME and standardized ileal digestibility (SID) values of AA for a novel high-protein distillers dried grains with solubles (HP-DDGS; PureStream 40, Lincolnway Energy LLC, Nevada, IA) to determine the optimal dietary inclusion rates in diets for nursery pigs. Three hundred and sixty pigs (BW = 6.79 ± 0.02 kg) were blocked by BW, and pens within blocks were assigned randomly to one of four dietary treatments (10 pens/treatment, 9 pigs/pen). Dietary treatments consisted of adding 0%, 10%, 20%, or 30% HP-DDGS to nursery diets during phase 2 (days 7–21) and phase 3 (days 21–42) of a three-phase nursery feeding program. Diets within each phase were formulated to contain equivalent amounts of ME, SID Lys, Met, Thr, and Trp, Ca, standardized total tract digestible P, vitamins, and trace minerals. Calculated SID Leu to Lys ratios for 0%, 10%, 20%, and 30% HP-DDGS diets were 119%, 137%, 156%, and 173% in phase 2 diets and 120%, 131%, 143%, and 160% in phase 3 diets. The SID Ile to Lys ratios ranged from 60% to 69% in

phase 2 diets and from 54% to 59% in phase 3 diets. The SID Val to Lys ratios ranged from 63% to 79% in phase 2 diets and 64% to 68% in phase 3 diets. Body weight and feed disappearance were measured weekly. During phase 2, ADG, ADFI, and G:F were reduced linearly ( $P < 0.01$ ) as the diet inclusion rate of HP-DDGS increased. Similarly in phase 3, increasing dietary levels of HP-DDGS depressed ADG, ADFI, and G:F linearly ( $P < 0.01$ ). Overall growth performance of phases 2 and 3 of nursery pigs was negatively affected by increasing levels of HP-DDGS in these diets. Pigs acquired a *Streptococcus suis* and *Escherichia coli* disease challenge during the experiment. Although no differences in morbidity were observed throughout the experiment, including HP-DDGS in diets tended to decrease ( $P = 0.08$ ) mortality. In conclusion, a linear decrease in nursery pig growth performance was observed as increasing levels of HP-DDGS were added in diets, which was probably due to overestimation of SID AA content of the HP-DDGS, antagonistic effects of excess Leu, and the effects of relatively high fiber content.

**Key words:** branched-chain amino acids, growth performance, high-protein distillers dried grains, leucine, nursery pigs

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<sup>2</sup>Corresponding author: [shurs001@umn.edu](mailto:shurs001@umn.edu)

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## INTRODUCTION

New technologies have been developed and implemented in ethanol plants to improve production efficiency. One of the new corn coproducts

being produced is high-protein distillers dried grains with solubles (**HP-DDGS**). Previously, HP-DDGS was produced using front-end fractionation processes; however, new processes are currently being used by some ethanol plants to produce HP-DDGS with a different nutritional profile. A novel HP-DDGS source (PureStream 40; Lincolnway Energy LLC, Nevada, IA) is being produced by using advanced technologies including Selective Milling Technology (ICM, Inc., Colwich, KS) to separate various fractions of corn before fermentation, and a compression drying system (Rayeman Elements, Inc., Berthoud, CO) to remove moisture using relatively low temperatures (<90 °C). Recently determined ME and standardized ileal digestibility (**SID**) values of AA for this HP-DDGS source indicate that it has greater nutritional value than conventional DDGS sources (Espinosa and Stein, 2018). However, a potential problem with the use of high-protein corn coproducts is the excess leucine and imbalance of branched-chain AA (**BCAA**) relative to lysine. Therefore, increasing diet inclusion of HP-DDGS sources may lead to excess dietary leucine, which can interfere with utilization of the other BCAA, valine and isoleucine (Harris et al., 2004). The ultimate result may be reduced feed intake and growth rate of pigs (Gloaguen et al., 2012). However, no studies have been conducted to evaluate growth performance of nursery pigs fed this new HP-DDGS source. Previous studies (Stein and Shurson, 2009; Tran et al., 2012; Wiseman et al., 2017) have shown that DDGS can be added to nursery diets at concentrations up to 30% to achieve satisfactory growth performance, but it is unclear if a similar inclusion rate of this new HP-DDGS source will provide similar growth performance responses. Therefore, the objective of this study was to determine the optimal dietary inclusion rate of this new HP-DDGS source in phase 2 and phase 3 nursery diets.

## MATERIALS AND METHODS

The experimental protocol used in this study was approved by the University of Minnesota Institutional Animal Care and Use Committee (protocol #1706-34880A).

### *Animal and Housing*

Weaned pigs ( $n = 360$ ; initial BW =  $6.79 \pm 0.02$  kg) that were the offspring of PIC Line 42 sows mated to Line 359 sires (Pig Improvement Company, Hendersonville, TN) were obtained from a commercial farm located near the

University of Minnesota West Central Research and Outreach Center in Morris, MN. Forty nursery pens ( $2.4 \text{ m} \times 1.2 \text{ m}$ ) located in two similar rooms in a confinement nursery facility were used. All pigs had ad libitum access to feed and water throughout the experimental period. Pigs were observed daily to evaluate health and to ensure that the waterers and feeders were functioning properly.

Pigs were assigned to blocks based on initial BW, and blocks were randomly assigned to 40 pens (nine pigs/pen). Pens within blocks were then assigned randomly to one of four dietary treatments. The ratio of gilts and barrows within pens was equalized within blocks and treatments.

### *Dietary Treatments*

The HP-DDGS source used in this experiment was obtained in a single batch from Lincolnway Energy, LLC. Samples were collected and sent to Midwest Laboratories (Omaha, NE) for analysis (Table 1). Analysis was performed following standard AOAC (2012) procedures for moisture (AOAC 930.15), CP (AOAC 990.03), ether extract (AOAC 945.16), NDF (AOAC 2001.11/Ankom 200 Fiber Analyzer with F57 filter bags, Ankom Technology, Macedon, NY), Ca and P (AOAC 985.01), AA profile (AOAC 994.12 including sections a, b, and c for hydrolysis of cysteine, methionine, and tryptophan), and mycotoxins (AOAC 2008.02; modified to use a multitoxin immunoaffinity column that measures multiple mycotoxins using liquid chromatography/mass spectrometry/mass spectrometry [LC/MS/MS]). Low concentrations of deoxynivalenol (1.09 mg/kg) and total fumonisins (3.24 mg/kg) were present in this HP-DDGS source.

A three-phase feeding program was used. All pigs received the same commercial phase 1 diet (Vita Plus, Madison, WI) for 7 d, followed by feeding their assigned phase 2 experimental diets for a 14 d (days 8 to 21 postweaning) and phase 3 diets (days 22 to 42) for an additional 21 d. Experimental diets for phases 2 and 3 were formulated to contain HP-DDGS at inclusion levels of 0%, 10%, 20%, or 30%. Analyzed nutrient composition of HP-DDGS samples was used along with recently published ME values and SID AA coefficients for this source of HP-DDGS (Espinosa and Stein, 2018) to formulate experimental diets. Metabolizable energy, nutrient composition, and digestibility values for all other ingredients were obtained from NRC (2012). Diets within each phase were formulated to contain similar concentrations of ME, SID AA (Lys, Met, Thr, and Trp), Ca, standardized total tract digestible P,

**Table 1.** Analyzed nutrient composition and mycotoxin concentrations of high-protein distillers dried grain with solubles (HP-DDGS), as-fed basis<sup>1</sup>

Item	HP-DDGS
DM, %	89.27
CP, %	37.58
Ether extract, %	8.42
NDF, %	31.07
Ca, %	0.03
P, %	0.81
ME <sup>2</sup> , kcal/kg	3,698
Indispensable AA <sup>3</sup> , %	
Arg	1.80 (87.4)
His	1.03 (82.2)
Ile	1.45 (81.9)
Leu	4.59 (89.2)
Lys	1.37 (76.2)
Met	0.79 (87.2)
Phe	2.07 (85.5)
Thr	1.48 (75.0)
Trp	0.28 (79.5)
Val	1.92 (81.1)
Dispensable AA, %	
Ala	2.98 (84.5)
Asp	2.81 (72.9)
Cys	0.81 (74.9)
Glu	7.04 (87.5)
Pro	1.47 (ND)
Gly	3.21 (71.2)
Ser	2.11 (80.8)
Tyr	1.64 (86.5)
Mycotoxins <sup>4</sup>	
Fumonisin B1, mg/kg	2.48
Fumonisin B2, mg/kg	0.76
Deoxynivalenol, mg/kg	1.09

<sup>1</sup>HP-DDGS source used was Purestream 40 (Lincolnway Energy LLC, Nevada, IA).

<sup>2</sup>Metabolizable energy value obtained from [Espinosa and Stein \(2018\)](#).

<sup>3</sup>AA profile derived from analyzed composition (Midwest Laboratories, Omaha, NE); numbers in parenthesis are standardized ileal digestibility coefficients from [Espinosa and Stein \(2018\)](#). ND = not determined.

<sup>4</sup>Mycotoxin analysis was performed at Midwest Laboratories (Omaha, NE). Analytical values for mycotoxins not listed were below detectable concentrations (Aflatoxin B1, B2, G1, G2, T-2 toxin, ochratoxin, and zearalenone).

vitamins, and minerals ([Tables 2 and 3](#)). In phases 2 and 3, increasing diet inclusion rates of HP-DDGS resulted in substantial increases in SID Leu concentration, but not SID Ile or Val. All diets were formulated to meet or exceed [NRC \(2012\)](#) requirements for nursery pigs. Diets were fed in meal form and contained no mycotoxin mitigation additives, antibiotics, or other growth promoting additives. Diet composition was subsequently analyzed at

University of Missouri Agricultural Experiment Station Chemical Laboratory (AESCL; Columbia, MO) for CP (AOAC 984.13 Kjeldahl) and AA profile (AOAC 982.30 including sections a and b for hydrolysis of cysteine and methionine). Mycotoxin concentrations of all the experimental diets were determined at North Dakota State University Veterinary Diagnostic Laboratory (Fargo, ND), where mycotoxins were extracted in acetonitrile water followed by LC/MS/MS detection ([Varga et al., 2012](#)).

### Health Management

During this experiment, pigs experienced an unintended *Streptococcus suis* and *Escherichia coli* infections, which were diagnosed based on clinical signs and necropsy results. The attending veterinarian prescribed administration of amoxicillin to all pigs through the drinking water, and individual pigs were also administered injections of penicillin (DURVET, Blue Springs, MO) and/or ceftiofur (Zoetis Inc., Kalamazoo, MI) when necessary. All deaths, removals, and medication treatments were recorded and used to calculate morbidity and mortality among dietary treatments.

### Data Collection

Individual pig BW was measured initially and weekly thereafter to calculate ADG. Feed disappearance was measured weekly at the same time as pigs were weighed, by subtracting the weight of feed remaining in feeders from the total amount of feed added to each feeder to determine ADFI on a pen basis. Pen weight gain and feed disappearance during each weekly period were used to calculate G:F. Morbidity was calculated as the percentage of individual pigs treated with injectable antibiotics. Mortality was calculated as the percentage of pigs that died in each dietary treatment during the experiment.

### Statistical Analysis

Growth performance data were analyzed statistically as a randomized complete block design using the PROC GLIMMIX procedure with repeated measurements in SAS 9.4 (SAS Inst. Inc., Cary, NC). Pen was used as the experimental unit. Dietary treatments were considered as fixed effects and blocks were random effects. Linear and quadratic orthogonal polynomial contrasts were tested using the CONTRAST option of SAS.

**Table 2.** Composition of phase 2 (days 7 to 21) nursery diets (as-fed basis)

Item	HP-DDGS inclusion rate <sup>1</sup>			
	0%	10%	20%	30%
<b>Ingredients, %</b>				
Corn	51.80	45.88	39.96	34.21
Soybean meal	19.30	16.10	12.90	9.52
HP-DDGS	0.00	10.00	20.00	30.00
Whey powder	15.00	15.00	15.00	15.00
Soy protein isolate	8.00	8.00	8.00	8.00
Soybean oil	2.07	1.38	0.69	0.00
Monocalcium phosphate	0.97	0.74	0.51	0.29
Limestone	1.38	1.52	1.65	1.78
L-Lys	0.39	0.38	0.37	0.37
DL-Met	0.15	0.11	0.07	0.03
L-Thr	0.14	0.09	0.05	0.00
Vit-TM premix <sup>2</sup>	0.50	0.50	0.50	0.50
Salt	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
<b>Calculated composition</b>				
DM, %	90.11	90.29	90.48	90.67
CP, %	22.56	24.19	25.82	27.37
NDF, %	6.32	8.71	11.11	13.50
ME, kcal/kg	3,400	3,400	3,400	3,400
<b>SID AA<sup>3</sup></b>				
Arg, %	1.29	1.33	1.36	1.39
His, %	0.51	0.55	0.58	0.62
Ile, %	0.85	0.89	0.94	0.98
Leu, %	1.69	1.95	2.21	2.46
Lys, %	1.42	1.42	1.42	1.42
Met, %	0.44	0.44	0.44	0.44
Phe, %	0.94	1.03	1.12	1.20
Thr, %	0.86	0.86	0.86	0.86
Trp, %	0.25	0.25	0.25	0.25
Val, %	0.90	0.98	1.05	1.12
<b>SID branched-chain AA:Lys</b>				
Leu:Lys	1.19	1.37	1.56	1.73
Ile:Lys	0.60	0.63	0.66	0.69
Val:Lys	0.63	0.69	0.74	0.79
Ca, %	0.84	0.84	0.84	0.84
STTD P <sup>4</sup> , %	0.42	0.42	0.42	0.42
Total Ca:STTD P	2.00	2.00	2.00	2.00
<b>Analyzed composition</b>				
CP, %	20.64	21.02	23.56	25.58
Arg, %	1.41	1.34	1.39	1.39
His, %	0.56	0.57	0.63	0.66
Ile, %	1.02	1.01	1.10	1.13
Leu, %	1.86	2.03	2.37	2.59
Lys, %	1.65	1.59	1.74	1.52
Met, %	0.48	0.38	0.45	0.41
Phe, %	1.11	1.12	1.24	1.29
Thr, %	0.98	0.93	0.98	0.97
Val, %	1.10	1.13	1.25	1.32
Fumonisin B1, mg/kg	ND <sup>5</sup>	0.321	0.479	0.767
Fumonisin B2, mg/kg	ND	ND	ND	0.267
Zearalenone, mg/kg	ND	ND	ND	0.125
Deoxynivalenol, mg/kg	0.389	0.367	0.522	0.667

<sup>1</sup>HP-DDGS = high-protein distillers dried grain with solubles (PureStream 40; Lincolnway Energy, LLC, Nevada, IA).

<sup>2</sup>Vitamin and trace mineral premix supplied the following nutrients per kilogram of premix: 2,200,000 IU of vitamin A; 550,000 IU of vitamin D<sub>3</sub>; 17,600 IU of vitamin E; 880 mg of vitamin K; 1,980 mg of riboflavin; 11,000 mg of niacin; 6,600 mg of pantothenic acid; 99,000 mg of choline; 11 mg of vitamin B<sub>12</sub>; 440 mg of pyridoxine; 330 mg of folic acid; 220 mg of thiamine; 66 mg of biotin; 440 mg of EDDI iodine; 59 mg of organic selenium; 40 mg of chromium; 18,000 mg of SQM zinc (QualiTech, Chaska, MN); 11,000 mg of SQM iron; 1,500 mg of SQM copper; 3,500 mg of SQM manganese.

<sup>3</sup>SID AA = standardized ileal digestible AA.

<sup>4</sup>STTD P = standardized total tract digestible phosphorus.

<sup>5</sup>ND = not detected. Feed samples from each treatment were obtained after mixing.

Mean values were expressed as least square means. Morbidity and mortality rates were analyzed using the chi-square test in the FREQ procedure of SAS. Effects were considered significant at  $P < 0.05$ , and trends were reported at  $0.05 < P < 0.10$ .

## RESULTS AND DISCUSSION

Initial BW ( $6.79 \pm 0.02$  kg) was not different among treatments, but differences in BW among dietary treatments began to appear at the end of phase 2 and continued throughout the remainder of the experiment (Table 4). Pig BW decreased linearly ( $P < 0.01$ ) when dietary levels of HP-DDGS increased. During phase 2, overall ADG, ADFI, and G:F were reduced linearly ( $P < 0.01$ ) as HP-DDGS inclusion rate increased in diets. Similarly, increasing dietary HP-DDGS levels decreased ADG, ADFI, and G:F linearly ( $P < 0.01$ ) during the phase 3 period. As a result, overall ADG and ADFI during phases 2 and 3 were linearly reduced ( $P < 0.01$ ) with increasing inclusion rates of HP-DDGS, and there was a time  $\times$  treatment interaction ( $P < 0.01$ ). The interaction indicated that the magnitude of depression in growth rate and feed intake was greater in phase 3 than in phase 2. In addition, overall G:F was linearly reduced ( $P < 0.01$ ) as dietary HP-DDGS level increased, but there was no time  $\times$  treatment interaction.

No studies have been published to provide information on the use of this new HP-DDGS source in swine nursery diets, but several studies have been published to evaluate the effects of adding up to 30% DDGS to nursery diets. Stein and Shurson (2009) summarized 10 experiments involving feeding diets containing up to 30% corn DDGS to nursery pigs and reported that none of the studies showed changes in ADG, only two studies showed reductions in ADFI, and five studies showed improvements in G:F. These results indicate that if accurate ME and SID AA values for DDGS are used in diet formulation, no negative effects on growth performance should be observed when diets containing high quality DDGS are fed to swine. Tran et al. (2012) showed no effects on growth performance when a diet containing 30% DDGS was fed in the late nursery period (phase 3), but pigs fed a 30% DDGS diet had reduced ADG and ADFI in phase 2. Wiseman et al. (2017) reported that feeding 25% DDGS diets in phases 2 and 3 of the nursery

Mycotoxin analysis was performed using liquid chromatography/mass spectrometry–mass spectrometry at North Dakota State University Veterinary Diagnostic Laboratory (Fargo, ND). Analytical values for mycotoxins not listed were all below detectable concentrations (Aflatoxin B1, B2, G1, G2, HT-2 toxin, T-2 toxin, ochratoxin A, and sterigmatocystin).

**Table 3.** Composition of phase 3 (days 21 to 42) nursery diets (as-fed basis)

Item	HP-DDGS inclusion rate <sup>1</sup>			
	0%	10%	20%	30%
<b>Ingredients, %</b>				
Corn	61.24	59.68	58.10	53.39
Soybean meal	32.42	24.66	16.88	12.44
HP-DDGS	0.00	10.00	20.00	30.00
Soybean oil	2.60	1.82	1.04	0.31
Monocalcium phosphate	0.98	0.81	0.64	0.42
Limestone	1.28	1.42	1.57	1.70
L-Lys	0.41	0.54	0.67	0.70
DL-Met	0.14	0.12	0.10	0.06
L-Thr	0.13	0.14	0.16	0.13
L-Trp	0.00	0.01	0.04	0.05
Vit-TM premix <sup>2</sup>	0.50	0.50	0.50	0.50
Salt	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
<b>Calculated composition</b>				
DM, %	88.63	88.76	88.90	89.07
CP, %	21.09	21.10	21.12	22.30
NDF, %	8.24	10.66	13.07	15.47
ME, kcal/kg	3,400	3,400	3,400	3,400
<b>SID AA<sup>3</sup></b>				
Arg, %	1.25	1.15	1.05	1.05
His, %	0.50	0.49	0.49	0.50
Ile, %	0.76	0.73	0.69	0.71
Leu, %	1.54	1.69	1.84	2.07
Lys, %	1.29	1.29	1.29	1.29
Met, %	0.42	0.42	0.42	0.42
Phe, %	0.89	0.90	0.90	0.97
Thr, %	0.77	0.77	0.77	0.77
Trp, %	0.22	0.22	0.22	0.22
Val, %	0.82	0.82	0.82	0.87
<b>SID branched-chain AA:Lys</b>				
Leu:Lys	1.20	1.31	1.43	1.60
Ile:Lys	0.59	0.56	0.54	0.55
Val:Lys	0.64	0.64	0.64	0.68
Ca, %	0.74	0.74	0.74	0.74
STTD P <sup>4</sup> , %	0.35	0.35	0.35	0.35
Total Ca:STTD P	2.12	2.12	2.12	2.12
<b>Analyzed composition</b>				
CP, %	19.17	19.54	20.07	20.80
Arg, %	1.25	1.06	1.04	0.95
His, %	0.51	0.48	0.52	0.51
Ile, %	0.87	0.79	0.85	0.80
Leu, %	1.62	1.71	2.02	2.15
Lys, %	1.44	1.40	1.41	1.37
Met, %	0.51	0.35	0.37	0.31
Phe, %	0.98	0.91	1.00	0.99
Thr, %	0.91	0.85	0.87	0.84
Val, %	0.96	0.90	0.99	0.98
Fumonisin B1, mg/kg	ND <sup>5</sup>	0.324	0.606	0.782
Fumonisin B2, mg/kg	ND	ND	ND	0.261
Zearalenone, mg/kg	ND	ND	ND	0.262
Deoxynivalenol, mg/kg	0.288	0.302	0.412	0.559

<sup>1</sup>HP-DDGS = high-protein distillers dried grain with solubles (PureStream 40; Lincolnway Energy, LLC, Nevada, IA).

<sup>2</sup>Vitamin and trace mineral premix supplied the following nutrients per kilogram of premix: 2,200,000 IU of vitamin A; 550,000 IU of vitamin D<sub>3</sub>; 17,600 IU of vitamin E; 880 mg of vitamin K; 1,980 mg of riboflavin; 11,000 mg of niacin; 6,600 mg of pantothenic acid; 99,000 mg of choline; 11 mg of vitamin B<sub>12</sub>; 440 mg of pyridoxine; 330 mg of folic acid; 220 mg of thiamine; 66 mg of biotin; 440 mg of EDDI iodine; 59 mg of organic selenium; 40 mg of chromium; 18,000 mg of SQM zinc (QualiTech, Chaska, MN); 11,000 mg of SQM iron; 1,500 mg of SQM copper; 3,500 mg of SQM manganese.

<sup>3</sup>SID AA = standardized ileal digestible AA.

<sup>4</sup>STTD P = standardized total tract digestible phosphorus.

<sup>5</sup>ND = not detected. Feed samples from each treatment were obtained after mixing. Mycotoxin analysis was performed using liquid chromatography/mass spectrometry–mass

period decreased ADFI, but there were no differences in BW, ADG, or G:F compared with pigs fed corn–soybean meal control diets.

A limited number of studies have reported reductions in ADFI when 15% DDGS diets (Barbosa et al., 2008), 25% DDGS (Wiseman et al., 2017), or 30% DDGS diets (Tran et al., 2012) were fed to nursery pigs. However, this effect has not commonly been observed in the majority of other published studies. Some researchers have suggested that the relatively high fiber content in DDGS may cause a reduction in feed intake because fiber increases the bulk volume in the gastrointestinal tract, which limits gut capacity, and thereby decreases voluntary feed intake in pigs (Nyachoti et al., 2004; Avelar et al., 2010). The source of HP-DDGS used in the current experiment contained 31% NDF, which linearly increased NDF content of diets, and may have partially contributed to the reduction in feed intake. In addition, Seabolt et al. (2010) observed a linear decrease in feed consumption and preferences for diets containing DDGS and HP-DDGS in nursery pigs, which may have been due to reduced palatability. Therefore, it is possible that both the high fiber content and potential palatability issues in the HP-DDGS diets may have contributed to the reduced feed intake observed in the current experiment, which subsequently reduced ADG with increasing dietary HP-DDGS content.

Another possible explanation for the linear decrease in ADG with increasing HP-DDGS concentration is that feeding diets with high fiber content can affect the requirement for Thr (Mathai et al., 2016). Dietary fiber has been shown to increase gastrointestinal production of mucin, which serves as an intestinal barrier (Satchithanandam et al., 1996), but mucin is poorly digested for reabsorption and is considered as a major contributor to endogenous AA losses (Urriola et al., 2013). Threonine is the most abundant indispensable AA in mucin; therefore, dietary fiber-induced mucin secretion leads to increased loss of Thr (Stein et al., 1999; Zhu et al., 2005). As a result, the required SID Thr to Lys ratio increases when feeding high fiber diets with 17% NDF and 10% ADF (Mathai et al., 2016). The recommended SID Thr to Lys ratio should be greater than 0.60 if diets contain more than 11% NDF (Mathai et al., 2017). In our phases 2 and 3 diets, NDF concentrations were greater than 11% for the

spectrometry at North Dakota State University Veterinary Diagnostic Laboratory (Fargo, ND). Analytical values for mycotoxins not listed were all below detectable concentrations (Aflatoxin B1, B2, G1, G2, HT-2 toxin, T-2 toxin, ochratoxin A, and sterigmatocystin).

**Table 4.** Effects of increasing dietary levels of a new high-protein corn distillers dried grains with solubles (HP-DDGS) on growth performance, morbidity, and mortality during the nursery feeding period

Item	HP-DDGS inclusion rate, %				SEM	Probability	
	0	10	20	30		Linear	Quadratic
<b>BW<sup>1</sup></b>							
Day 7, kg	6.78	6.79	6.79	6.79	0.01	0.78	0.93
Day 14, kg	8.10	8.03	7.91	7.90	0.10	0.14	0.77
Day 21, kg	11.26	10.94	10.50	10.56	0.34	0.01	0.28
Day 28, kg	14.68	14.08	13.29	13.12	0.78	0.01	0.34
Day 35, kg	18.01	17.27	16.40	15.90	0.94	0.01	0.66
Day 42, kg	23.44	22.30	20.97	19.99	1.51	0.01	0.81
<b>Phase 2 (days 7 to 21)</b>							
ADG, kg	0.32	0.30	0.26	0.27	0.01	0.01	0.22
ADFI, kg	0.40	0.38	0.36	0.36	0.01	0.01	0.46
G:F	0.81	0.77	0.73	0.74	0.01	0.01	0.10
<b>Phase 3 (days 22 to 42)</b>							
ADG, kg	0.58	0.54	0.50	0.45	0.02	0.01	0.51
ADFI, kg	0.88	0.86	0.80	0.74	0.03	0.01	0.39
G:F	0.66	0.63	0.63	0.60	0.01	0.01	0.99
<b>Overall (days 7 to 42)</b>							
ADG <sup>1</sup> , kg	0.47	0.44	0.41	0.38	0.01	0.01	0.75
ADFI <sup>1</sup> , kg	0.68	0.67	0.62	0.59	0.02	0.01	0.59
G:F <sup>2</sup>	0.70	0.67	0.66	0.65	0.01	0.01	0.13
Morbidity <sup>3</sup> , %	16.5	8.8	20.9	4.4	0.01	NA <sup>5</sup>	NA
Mortality <sup>4</sup> , %	11.0	3.3	3.3	4.4	0.01	NA	NA

<sup>1</sup>Time effect ( $P < 0.01$ ) and time  $\times$  treatment interaction ( $P < 0.01$ ).

<sup>2</sup>Time effect ( $P < 0.01$ ).

<sup>3</sup>No treatment effect ( $P = 0.32$ ).

<sup>4</sup>Trend of dietary treatment effect ( $P = 0.08$ ).

<sup>5</sup>NA = not applicable.

20% and 30% HP-DDGS diets, and SID Thr to Lys ratios were 0.61 in phase 2 and 0.60 in phase 3. We suspect that the SID Thr to Lys ratios may have been inadequate in the high HP-DDGS diets that contained 13% to 15% NDF in the present study.

Achieving optimal AA nutrition is also based on accurate estimates of the SID Lys and AA content. The ME content and standardized ileal digestibility (SID) of AA for this HP-DDGS source were recently determined (Espinosa and Stein, 2018). Although nutrient composition of the HP-DDGS source used in that experiment was similar to the HP-DDGS source used in the present study, the ME and SID AA content were determined in 75-kg growing pigs and not in weaned pigs. Using SID AA coefficients and ME values derived from growing pigs may have resulted in overestimation of the AA digestibility in the new HP-DDGS source fed to nursery pigs in the present study. Nitrayová et al. (2006) reported that heavier weight pigs have greater apparent ileal digestibility (AID) of AA and total N than lighter BW pigs. Furthermore, weaning pigs have greater basal endogenous AA secretion compared with growing pigs (Adeola et al.,

2016). Both findings imply that the SID coefficient for AA may be less in nursery pigs than in growing pigs. In addition, the AA content and digestibility can vary within an HP-DDGS source. Rho et al. (2017) showed that SID coefficients for Lys can vary from 47% to 56% for HP-DDGS samples collected from the same ethanol plant at different time points. The HP-DDGS source used in the current experiment was from the same ethanol plant as the source used by Espinosa and Stein (2018), but samples collected at different time points could have resulted in differences in AA digestibility. Therefore, using SID AA coefficients derived from growing pigs may have resulted in overestimation of SID AA in the HP-DDGS source fed to nursery pigs in the present study.

Corn coproducts contain relatively high concentrations of Leu, but not the other BCAA, Val and Ile. The excess dietary SID Leu content in diets with high inclusion rates of HP-DDGS may have contributed to the reduced ADFI and ADG observed in this study. Comparing the 0% vs. 30% HP-DDGS diets in phase 2 (Table 2), the SID Leu to Lys ratio increased from 119% to 173%, whereas

SID Ile:Lys increased from 60% to 69% and SID Val:Lys increased from 63% to 79%. Similarly, when comparing the SID BCAA to Lys ratios in the 0% vs. 30% HP-DDGS phase 3 diets (Table 3), SID Leu:Lys increased from 120% to 160%, whereas SID Ile:Lys was relatively stable and only changed from 59% to 55%, and SID Val:Lys increased from 64% to 68%. Excessive Leu intake reduces Val and Ile concentrations in blood and muscle because of BCAA antagonism, which has been observed in humans, rats, poultry, and pigs (Harper et al., 1984). Excessive dietary BCAA will activate degradation pathways to maintain the balance via branched-chain keto acid dehydrogenase complex (Harper et al., 1984). Interestingly, this enzyme complex is shared by all three BCAA, where high dietary Leu not only induces degradation of Leu, but also induces degradation of Val and Ile, which can cause Val and Ile to be less available or deficient (Harris et al., 2004). As a result, animals require greater dietary concentrations of Val and Ile for optimal growth under high Leu intake. Htoo et al. (2017) showed that the optimal SID Ile to Lys ratio increased from 54% to 58% when Leu:Lys increased from 110% to 160% for 8 to 25 kg pigs, which indicated that SID Ile may not have been optimal in some of the HP-DDGS diets in the present study. Wiltafsky et al. (2010) suggested that growth depressing effects can be observed when SID Leu:Ile exceeds 2.33 or SID Leu:Val exceeds 1.79. The SID Leu:Ile of diets in the present study was calculated to be 1.99, 2.19, 2.35, and 2.51 in phase 2 and 2.03, 2.32, 2.67, and 2.92 in phase 3 diets with increasing levels of HP-DDGS. The SID Leu:Val was calculated to be 1.88, 1.99, 2.10, and 2.20 in phase 2 and 1.88, 2.06, 2.24, and 2.38 in phase 3. Clearly, including 20% and 30% HP-DDGS in our diets resulted in an excessive amount of Leu and an inadequate amount of Val and Ile, which probably contributed to the reduced growth performance observed with increasing dietary HP-DDGS concentration.

The analyzed CP and AA concentrations in all diets were less than expected based on formulated values. Lower than expected AA content and subsequent reductions in ADFI may have contributed to the linear reduction in ADG and G:F. However, diets were formulated using a 5% safety margin above NRC (2012) requirements for SID Lys, Met, Thr, and Trp to account for variability in feed ingredient SID AA content. We speculate that less than expected AA content in these diets may not have been the only reason that we observed a reduction in growth performance. In fact, the 20% HP-DDGS diet in phase 2 had the highest analyzed Lys and Thr

content among all phase 2 diets, but growth performance was reduced, which suggests that the other factors previously described may have contributed to this response and require further investigation.

The HP-DDGS source fed in this study also contained 1.09 mg/kg deoxynivalenol, 2.48 mg/kg fumonisin B1, and 0.76 mg/kg fumonisin B2. Very low concentrations of deoxynivalenol were detected in the 0% HP-DDGS diets for phase 2 (0.389 mg/kg) and phase 3 (0.288 mg/kg), which suggested that the corn used in this experiment contained low but detectable concentrations of deoxynivalenol. Fumonisin B1 was present in low concentrations in all HP-DDGS diets fed in phases 2 and 3, but there were no detectable levels of fumonisin B2 and zearalenone in diets in both phases except when 30% HP-DDGS was added. Recommendations for “safe” maximum concentrations of deoxynivalenol (<1 mg/kg) and total fumonisins (5 mg/kg) in growing-finishing pig diet are commonly used as a guide to determine relative risk of growth performance reductions when feeding mycotoxin-contaminated diets (Thaler and Reese, 2010). The concentrations of these mycotoxins in all diets in the present study were well below these maximum recommended limits. However, there are no specific recommended maximum threshold concentrations for mycotoxins in nursery pig diets (Thaler and Reese, 2010). As a result, it is possible, but unlikely that the low concentrations of deoxynivalenol and fumonisins present in diets fed in the current study may have partially contributed to the reduction in ADFI and ADG observed.

During this study, 45 of 360 pigs (15 pigs fed 0% HP-DDGS, 8 pigs fed 10% HP-DDGS, 18 pigs fed 20% HP-DDGS, and 4 pigs fed 30% HP-DDGS diets) were administered medication, and 20 of 360 pigs (10 pigs fed 0% HP-DDGS, 3 pigs fed 10% HP-DDGS, 3 pigs fed 20% HP-DDGS, and 4 pigs fed 30% HP-DDGS diets; Table 4) were removed from the study due to poor health. There was no effect of dietary treatment on morbidity, but there was a trend ( $P = 0.08$ ) for a reduction in mortality with increasing dietary HP-DDGS inclusion rates. In this experiment, HP-DDGS was used to partially replace corn and soybean meal in the diets. Kim et al. (2015) have documented that soybean meal has antigenic effects on the immune system of young pigs when initially consuming soybean meal. Soybean meal contains various antinutritional factors such as trypsin inhibitors, oligosaccharides, and lectins. Therefore, using HP-DDGS in the diets to partially replace soybean meal may reduce the effects of these antinutritional factors, especially

when pigs had co-occurring disease challenges. Corn coproducts also contain residual yeast in various amounts, and yeast cell walls contain mannans (Miguel et al., 2004; Halas and Nochta, 2012),  $\beta$ -glucans (Dritz et al., 1995; Li et al., 2006; Kogan and Kocher, 2007), and nucleotides (Martinez-Puig et al., 2007; Sauer et al., 2011), which have positive effects on the immune system (Hassan, 2011). Moreover, Mendoza (2010) reported that insoluble dietary fiber from corn DDGS accelerated the recovery of weaning pigs from a postweaning *E. coli* infection. As a result, the use of HP-DDGS may have resulted in positive effects on animal mortality during the unintended disease challenge, but no effect on morbidity.

In conclusion, feeding increasing dietary levels of HP-DDGS linearly reduced ADG, ADFI, and G:F in nursery pigs, which may have been a result of overestimation of SID AA content of the HP-DDGS source fed, antagonistic effects of excess Leu resulting in suboptimal Val and Ile utilization, and the relatively high fiber content of the HP-DDGS diets, which may have contributed to marginal SID Thr content at high inclusion rates. Greater concentrations of dietary Val, Ile, and Thr may be needed to effectively incorporate this new HP-DDGS into nursery diets to achieve optimal growth performance. Feeding increasing dietary levels of HP-DDGS diets tended to reduce mortality in nursery pigs subjected to an unintended *S. suis* and *E. coli* disease challenge, which warrants further investigation.

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