# High-protein distillers dried grains with solubles produced using a novel front-end–back-end fractionation technology has greater nutritional value than conventional distillers dried grains with solubles when fed to growing pigs[1]

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**ABSTRACT:** Two experiments were conducted to determine the standardized ileal digestibility **(SID)** of CP and AA, apparent total tract digestibility **(ATTD)** of GE, and DE and ME in conventional distillers dried grains with solubles (**DDGS-CV**) and in a novel source of high-protein distillers dried grains with solubles (**DDGS-HP**) produced by Lincolnway Energy (Nevada, IA). In Exp. 1, 18 barrows (initial BW: 72.47 ± 9.16 kg) that had a T-cannula installed in the distal ileum were allotted to a completely randomized design with 3 diets and 6 replicate pigs per diet. A nitrogen-free diet and 2 diets that contained cornstarch and DDGS-CV or DDGS-$HP_{Lincolnway}$ as the sole source of CP and AA were formulated. Diets were fed to pigs for 7 d, and ileal digesta were collected on days 6 and 7 of each period. The SID for Leu, Lys, Met, Phe, and Glu was greater ($P < 0.05$) in DDGS-$HP_{Lincolnway}$ than in DDGS-CV, and the SID of Ile, Val, and total indispensable AA, as well as the SID of Tyr, tended to be greater ($P < 0.10$) in DDGS-$HP_{Lincolnway}$ than in DDGS-CV. No difference between DDGS-CV and DDGS-$HP_{Lincolnway}$ was observed for the SID of CP and all other AA. In Exp. 2, 24 barrows (initial BW: 52.80 ± 2.55 kg) were housed individually in metabolism crates and randomly allotted to 1 of 3 diets. A corn-based basal diet (97.25% corn) and 2 diets that contained corn and DDGS-CV or corn and DDGS-$HP_{Lincolnway}$ were formulated. Each diet was fed to 8 pigs. Feces and urine were collected using the marker to marker approach with 7-d adaptation and 5-d collection periods. The DE and ME in DDGS-CV and DDGS-$HP_{Lincolnway}$ were calculated using the difference procedure. The DE and ME in DDGS-$HP_{Lincolnway}$ on an as-fed basis were greater ($P < 0.05$) than in corn and DDGS-CV, but the ATTD of GE in DDGS-$HP_{Lincolnway}$ and DDGS-CV was less ($P < 0.01$) than in corn. In conclusion, the SID of some AA and the DE and ME in DDGS-$HP_{Lincolnway}$ were greater than in DDGS-CV.

**Key words:** AA digestibility, distillers dried grains with solubles, energy, pigs



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## INTRODUCTION

The dry-grind ethanol industry has evolved in recent years, and several different types of distillers dried grains with solubles (**DDGS**) are now produced. Separation of oil from the solubles results in production of low-oil DDGS (Kerr et al., 2013; Curry et al., 2016), and fractionation before or after fermentation may result in production of DDGS with higher protein concentration and several other coproducts (Widmer et al., 2007; Kim et al., 2009). Front-end fractionation of the grain results in production of high-protein distillers dried grains (**DDG-HP**) or high-protein DDGS (**DDGS-HP**; Rosentrater, 2012). High-protein DDG has greater digestibility of energy and AA, and greater concentration of DE and

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ME than corn, corn germ, or conventional DDGS (**DDGS-CV**; Widmer et al., 2007; Kim et al., 2009; Jacela et al., 2010). However, innovation in the ethanol industry has resulted in production of a new DDGS-HP product (**DDGS-HP$_{\textbf{Lincolnway}}$**), which is produced by Lincolnway Energy, Nevada, IA, and is marketed under the brand name PureStream Protein. The process to produce DDGS-HP$_{\text{Lincolnway}}$ involves a patented process to mechanically separate fiber based on its solubility before fermentation and an additional patented process to extract oil after fermentation. The DDGS-HP$_{\text{Lincolnway}}$ is dried using the patented Raymond Compression Drying System, which subjects the material to very little heat during the process. The DDGS-HP$_{\text{Lincolnway}}$ contains 38% to 44% CP in contrast to conventional DDGS, which contains approximately 27% CP (NRC, 2012). However, there are at this point no data to demonstrate the nutritional value of DDGS-HP$_{\text{Lincolnway}}$. Therefore, the objective of this research was to test the hypothesis that the apparent ileal digestibility **(AID)** and the standardized ileal digestibility **(SID)** of CP and AA, as well as the apparent total tract digestibility **(ATTD)** of GE and the DE and ME in DDGS-HP$_{\text{Lincolnway}}$ are greater than in DDGS-CV when fed to growing-finishing pigs.

## MATERIALS AND METHODS

The protocols for 2 experiments were approved by the Institutional Animal Care and Use Committee at the University of Illinois at Urbana–Champaign. Pigs that were the offspring of Line 359 boars mated to Camborough females (Pig Improvement Company, Hendersonville, TN) were used. The DDGS-CV and DDGS-HP$_{\text{Lincolnway}}$ that were used in the 2 experiments originated from the same batch of corn, and the same batches of DDGS-CV and DDGS-HP$_{\text{Lincolnway}}$ were used in both experiments (Table 1).

### *Experiment 1: AA Digestibility*

Experiment 1 was designed to determine the AID and SID of CP and AA in DDGS-HP$_{\text{Lincolnway}}$ and DDGS-CV. Three diets were formulated (Table 2). Two diets contained either DDGS-HP$_{\text{Lincolnway}}$ or DDGS-CV as the sole source of CP and AA. The third diet was a N-free diet that was used to determine basal endogenous losses of AA and CP. Vitamins and minerals were included in the diets to meet or exceed current requirement estimates (NRC, 2012). All diets contained 0.40% chromic oxide as an indigestible marker. Pigs were fed at a level of 3 times the maintenance energy requirement (i.e., 197 kcal ME per kg$^{0.60}$; NRC, 2012). The daily allotment of feed was divided into 2 equal meals and provided at 0800 and 1600 h, and water was available at all times.

Eighteen growing barrows (72.47 ± 9.16 kg) that had a T-cannula installed in the distal ileum were used. Pigs were placed in 1.2 × 1.5 m pens with fully slatted tri bar floors and all pigs had been used in a previous experiment before being fed a standard corn–soybean meal diet for 10 d and then being used in this experiment. Pigs were allotted to a completely randomized design with the 3 diets and 6 replicate pigs per diet. Diets were fed to pigs for 7 d. The initial 5 d were considered an adaptation period to the diets. Ileal digesta were collected on days 6 and 7 for 8 h using standard procedures (Stein et al., 1998). In short, the cannulas were opened, a 225-mL plastic bag was attached to the cannula barrel using a cable tie, and digesta flowing into the bag were collected. Bags were removed whenever they were full, or every 30 min, and replaced with a new. All samples were stored at −20 °C.

At the conclusion of the experiment, ileal digesta samples were thawed, mixed within animal and diet, and a subsample was collected for chemical analysis. Digesta samples were lyophilized and finely ground. Diet and ileal digesta samples were analyzed for chromium (Method 990.08; AOAC Int, 2007). Diets were also analyzed for GE using bomb calorimetry (Model 6300, Parr Instruments, Moline, IL). The 2 sources of DDGS, all diets, and all ileal digesta samples were analyzed for DM (Method 930.15; AOAC Int, 2007), for CP (Method 990.03; AOAC Int, 2007) using an Elementar Rapid N-cube Protein/Nitrogen apparatus (Elementar Americas Inc., Mt Laurel, NJ), and for AA (Method 982.30 E [a, b, c]; AOAC Int, 2007).

The AID and SID of CP and AA were calculated in the 2 diets containing DDGS-HP$_{\text{Lincolnway}}$ or DDGS-CV as previously described (Stein et al., 2007). The basal endogenous losses of CP and AA were calculated from pigs fed the N-free diet (Stein et al., 2007).

Data were analyzed as a completely randomized design with the pig as the experimental unit. An ANOVA was performed using the PROC MIXED function in SAS (SAS Institute Inc., Cary, NC). Homogeneity of the variances was confirmed using the UNIVARIATE procedure in PROC MIXED. Ingredient was the fixed effect, and pig and replicate were random effects. Least squares means were calculated using the LSMeans procedure, and means

**Table 1.** Analyzed chemical composition (as-fed basis) and physical characteristics of ingredients, Exp. 1 and 2[1]

| | Ingredient | | |
|---|---|---|---|
| Item | Corn | $DDGS\text{-}HP_{Lincolnway}$[2] | DDGS-CV[2] |
| CP, % | 7.59 | 37.11 | 29.47 |
| DM, % | 85.87 | 86.50 | 86.02 |
| GE, kcal/kg | 3,832 | 4,825 | 4,643 |
| Ash, % | 1.07 | 2.41 | 3.75 |
| ADF, % | 3.15 | 14.68 | 17.21 |
| NDF, % | 6.81 | 31.87 | 36.73 |
| IDF,[3] % | 9.80 | 31.80 | 34.00 |
| SDF,[3] % | 0.80 | 2.40 | 1.00 |
| TDF,[3] % | 10.60 | 34.20 | 35.00 |
| AEE,[4] % | 3.57 | 7.59 | 6.79 |
| Carbohydrates | | | |
| Glucose | 0.36 | 0.00 | 0.57 |
| Fructose | 0.21 | 0.00 | 0.32 |
| Sucrose | 1.57 | 0.00 | 0.00 |
| Raffinose | 0.18 | 0.00 | 0.00 |
| Stachyose | 0.00 | 0.00 | 0.00 |
| Starch | 67.7 | 2.4 | 3.7 |
| *L** | – | 78.38 | 71.03 |
| *a** | – | 4.16 | 7.93 |
| *b** | – | 28.25 | 28.33 |
| Bulk density, g/L | – | 601 | 573 |
| Particle size, μm | – | 569 | 585 |
| Indispensable AA, % | | | |
| Arg | 0.31 | 1.63 | 1.35 |
| His | 0.21 | 0.97 | 0.79 |
| Ile | 0.25 | 1.59 | 1.20 |
| Leu | 0.82 | 4.39 | 3.37 |
| Lys | 0.25 | 1.43 | 1.07 |
| Met | 0.18 | 0.70 | 0.54 |
| Phe | 0.36 | 2.03 | 1.66 |
| Thr | 0.26 | 1.39 | 1.14 |
| Trp | 0.06 | 0.30 | 0.26 |
| Val | 0.33 | 2.07 | 1.64 |
| Dispensable AA, % | | | |
| Ala | 0.56 | 2.58 | 2.02 |
| Asp | 0.55 | 2.44 | 1.88 |
| Cys | 0.22 | 0.69 | 0.57 |
| Glu | 1.22 | 5.61 | 3.81 |
| Gly | 0.30 | 1.45 | 1.30 |
| Ser | 0.32 | 1.46 | 1.23 |
| Tyr | 0.25 | 1.46 | 1.14 |
| All AA, % | 7.03 | 35.11 | 27.43 |
| Lys:CP ratio | 3.29 | 3.85 | 3.63 |

[1]$DDGS\text{-}HP_{Lincolnway}$ and DDGS-CV were used in both experiments, whereas corn was used only in Exp 2.

[2]$DDGS\text{-}HP_{Lincolnway}$ = high-protein distillers dried grains with solubles from Lincolnway Energy; DDGS-CV = conventional distillers dried grains with solubles.

[3]IDF = insoluble dietary fiber; SDF = soluble dietary fiber; TDF = total dietary fiber.

[4]AEE = acid hydrolyzed ether extract.

were separated using the PDIFF statement in SAS. Results were considered significant at $P < 0.05$ and considered a trend at $P < 0.10$.

### *Experiment 2: Energy Measurements*

Experiment 2 was conducted to determine the ATTD of GE and the DE and ME in corn, $DDGS\text{-}HP_{Lincolnway}$, and DDGS-CV. A corn-based basal diet and 2 diets containing corn and either $DDGS\text{-}HP_{Lincolnway}$ or DDGS-CV were formulated (Table 3). Vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 2012). A total of 24 barrows (52.80 ± 2.55 kg) were randomly allotted to the 3 diets with 8 pigs per diet. Pigs were housed individually in metabolism crates that were equipped with a self-feeder, a nipple waterer, and a slatted floor. A screen and a urine pan were placed under the slatted floor to allow for the total, but separate, collection of urine and fecal materials. Pigs were limit fed at 3 times the energy requirement for maintenance and feed was provided each day in 2 equal meals at 0800 and 1600 h. Throughout the study, pigs had ad libitum access to water. Feed consumption was recorded daily and pigs were fed experimental diets for 14 d. The initial 7 d was considered the adaptation period to the diet, whereas urine and fecal material were collected during the following 5 d according to standard procedures using the marker to marker approach (Adeola, 2001). Urine was collected in urine buckets over a preservative of 50 mL of 6*N* HCl. Fecal samples and 20% of the collected urine were stored at −20 °C immediately after collection. At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet, and a subsample was lyophilized before analysis (Kim et al., 2009).

Fecal samples were thawed and dried in a 50°C forced air drying oven and then ground through a 1-mm screen in a Wiley mill (Model 4; Thomas Scientific, Swedesboro, NJ). Diets and fecal samples were analyzed for DM, and ingredients (corn and both sources of DDGS), diets, fecal samples, and urine samples were analyzed for GE as explained for Exp. 1. Diets were also analyzed for CP (Method 990.03; AOAC Int, 2007) using a Kjeltec 8400 apparatus (FOSS Inc., Eden Prairie, MN). Ingredients were analyzed for ash (Method 942.05; AOAC Int, 2007) and acid hydrolyzed ether extract **(AEE)** by acid hydrolysis using 3*N* HCl (Ankom HCl Hydrolysis System, Ankom Technology, Macedon, NY) followed

**Table 2.** Composition (as-fed basis) of experimental diets, Exp. 1

| | Diet | | |
|---|---|---|---|
| Item | DDGS-HP$_{Lincolnway}$[1] | DDGS-CV[1] | Nitrogen free |
| Ingredients, % | | | |
| DDGS-HP$_{Lincolnway}$ | 37.00 | – | – |
| DDGS-CV | – | 50.00 | – |
| Soybean oil | 2.00 | 2.00 | 4.00 |
| Ground limestone | 1.00 | 1.25 | 0.50 |
| Monocalcium phosphate | 0.80 | 0.15 | 1.75 |
| Sucrose | – | – | 20.00 |
| Cornstarch | 58.10 | 45.50 | 68.15 |
| Solca flok[2] | – | – | 4.00 |
| Magnesium oxide | – | – | 0.10 |
| Potassium carbonate | – | – | 0.40 |
| Sodium chloride | 0.40 | 0.40 | 0.40 |
| Chromic oxide | 0.40 | 0.40 | 0.40 |
| Vitamin–mineral premix[3] | 0.30 | 0.30 | 0.30 |
| Analyzed composition | | | |
| DM, % | 91.85 | 91.85 | 94.97 |
| CP, % | 14.08 | 14.14 | 0.27 |
| GE, kcal/kg | 4,132 | 3,975 | 3,794 |
| Indispensable AA, % | | | |
| Arg | 0.65 | 0.71 | 0.01 |
| His | 0.38 | 0.43 | 0.00 |
| Ile | 0.63 | 0.66 | 0.02 |
| Leu | 1.72 | 1.87 | 0.03 |
| Lys | 0.58 | 0.58 | 0.02 |
| Met | 0.27 | 0.29 | 0.00 |
| Phe | 0.77 | 0.85 | 0.02 |
| Thr | 0.56 | 0.61 | 0.01 |
| Trp | 0.13 | 0.13 | 0.02 |
| Val | 0.81 | 0.87 | 0.02 |
| Dispensable AA, % | | | |
| Ala | 1.05 | 1.14 | 0.02 |
| Asp | 1.02 | 1.06 | 0.02 |
| Cys | 0.25 | 0.31 | 0.02 |
| Glu | 2.35 | 2.41 | 0.03 |
| Gly | 0.61 | 0.67 | 0.01 |
| Ser | 0.59 | 0.63 | 0.01 |
| Tyr | 0.53 | 0.57 | 0.01 |
| All AA, % | 14.10 | 15.11 | 0.40 |

[1]DDGS-HP$_{Lincolnway}$ = high-protein distillers dried grains with solubles from Lincolnway Energy; DDGS-CV = conventional distillers dried grains with solubles.

[2]Fiber Sales and Development Corp., Urbana, OH.

[3]Provided the following quantities of vitamins and micro minerals per kilogram 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.

by fat extraction (Ankom XT-15 Extractor, Ankom Technology, Macedon, NY). Ingredients were also analyzed for ADF and NDF (Ankom 2000 Fiber Analyzer, Ankom Technology, Macedon, NY), and for insoluble dietary fiber **(IDF)** and soluble dietary fiber according to method 991.43 (AOAC Int, 2007) using the Ankom$^{TDF}$ Dietary Fiber Analyzer (Ankom Technology, Macedon, NY). Total starch was analyzed in all ingredients using the glucoamylase procedure (Method 979.10; AOAC Int, 2007). Glucose, fructose, sucrose, stachyose, and raffinose were analyzed in all ingredients as described by Cervantes-Pahm and Stein (2010). Objective *L**, *a**, and *b** values for the 2 DDGS sources were determined using a Konica Minolta CR-400 (Konica Minolta Sensing Americas, Inc., William Drive Ramsey, NJ) with a D65 light source, a 0° observer, and an aperture size of 8 mm (Tavárez et al., 2011). Bulk density (Cromwell et al., 2000) and particle size of each source of DDGS were also determined (De Jong et al., 2016).

Following analysis, the ATTD of GE was calculated for each diet (NRC, 2012) and the DE and ME in each diet was calculated as well. The DE and ME of corn were calculated by dividing the DE and ME of the corn diet by the inclusion rate of corn in that diet. The contribution of DE and ME from corn to the DE and ME in the diets containing the 2 sources of DDGS was subtracted from the DE and ME of these diets, and the DE and ME of DDGS-HP$_{Lincolnway}$ and DDGS-CV were calculated by difference (Adeola, 2001). Data were analyzed as explained for Exp. 1.

## RESULTS

The CP of DDGS-CV used in the experiment was 29.47%, and the CP in DDGS-HP$_{Lincolnway}$ was 37.11% (Table 1). The Lys in DDGS-CV and DDGS-HP$_{Lincolnway}$ (as-fed basis) was 1.07 and 1.43%, respectively, which resulted in Lys being 3.63% and 3.85% of CP in DDGS-CV and DDGS-HP$_{Lincolnway}$, respectively.

### *Experiment 1: AA Digestibility*

Greater ($P < 0.05$) AID and SID for Leu, Lys, Met, Phe, and Glu were observed in DDGS-HP$_{Lincolnway}$ compared with DDGS-CV (Table 4). The SID of Ile, Val, and total indispensable AA, as well as the SID of Tyr, tended to be greater ($P < 0.10$) in DDGS-HP$_{Lincolnway}$ than in DDGS-CV.

### *Experiment 2: Energy Measurements*

Pigs fed the corn diet had reduced ($P < 0.01$) GE intake, fecal output, and fecal GE loss compared with pigs fed the DDGS-HP$_{Lincolnway}$ or

**Table 3.** Composition (as-fed basis) of experimental diets, Exp. 2

| | Diets | | |
|---|---|---|---|
| Item | Corn | DDGS-HP$_{Lincolnway}$[1] | DDGS-CV[1] |
| Ingredients, % | | | |
| Ground corn | 97.25 | 62.70 | 48.00 |
| DDGS-HP$_{Lincolnway}$ | – | 35.00 | – |
| DDGS-CV | – | – | 50.00 |
| Ground limestone | 0.75 | 1.05 | 1.30 |
| Monocalcium phosphate | 1.30 | 0.55 | – |
| Sodium chloride | 0.40 | 0.40 | 0.40 |
| Vitamin–mineral premix[2] | 0.30 | 0.30 | 0.30 |
| Analyzed composition | | | |
| DM, % | 86.07 | 86.89 | 87.46 |
| GE, kcal/kg | 3,696 | 4,100 | 4,189 |
| CP, % | 7.20 | 17.41 | 18.13 |

[1]DDGS-HP$_{Lincolnway}$ = high-protein distillers dried grains with solubles from Lincolnway Energy; DDGS-CV = conventional distillers dried grains with solubles.

[2]Provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin D3 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 B12, 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.

DDGS-CV diet (Table 5). There was no difference in GE intake between pigs fed diets containing DDGS-HP$_{Lincolnway}$ and DDGS-CV; however, pigs fed the DDGS-CV diet had greater ($P < 0.01$) fecal output and fecal GE loss compared with pigs fed the DDGS-HP$_{Lincolnway}$ diet. Pigs fed the DDGS-CV diet also tended to have greater ($P < 0.10$) urine output compared with pigs fed the corn diet, but urine output was not different between pigs fed the DDGS-HP$_{Lincolnway}$ diet and pigs fed the other diets.

The DE of the DDGS-HP$_{Lincolnway}$ diet was greater ($P < 0.05$) than the DE of the corn diet, but the DE of the DDGS-CV diet was not different from that of the other diets, and ME was not different among diets. The ATTD of GE in the corn diet was greater ($P < 0.01$) than in the DDGS-HP$_{Lincolnway}$ and the DDGS-CV diets.

The ATTD of GE in DDGS-HP$_{Lincolnway}$ and DDGS-CV (77.79% and 75.28%, respectively) was less ($P < 0.01$) than in corn. The DE and ME in DDGS-CV were 3,568 and 3,426 kcal/kg on as-fed basis, respectively, and 4,148 and 3,983 kcal/kg DM, respectively (Table 6). However, the DE and ME in DDGS-HP$_{Lincolnway}$ on an as-fed basis (3,826 and 3,698 kcal/kg, respectively) were greater ($P < 0.05$) than in corn and DDGS-CV. On a DM basis, the values for DE and ME in DDGS-HP$_{Lincolnway}$ (4,424 and 4,275 kcal/kg, respectively) were also greater ($P < 0.05$) than in corn, but not different from the DE and ME in DDGS-CV.

## DISCUSSION

The CP of DDGS-CV used in this experiment is within the range of reported values (Fastinger and Mahan, 2006; Stein et al., 2006; Stein and Shurson, 2009). Concentrations of CP, AA, GE, and AEE were greater in DDGS-HP$_{Lincolnway}$ compared with DDGS-CV, which is likely a result of the change in processing technology that was used to produce DDGS-HP$_{Lincolnway}$. The relatively high concentration of Lys in DDGS-CV and DDGS-HP$_{Lincolnway}$, which also resulted in a high Lys:CP ratio for both sources of DDGS, indicates that both sources of DDGS were less heat damaged than the DDGS produced in the past. Lysine is the most susceptible AA to destruction via the Maillard reaction due to its ε-amino group, which reacts with the reducing sugars in the presence of heat (Erbersdobler and Hupe, 1991) and DDGS produced in the past often had reduced concentration and digestibility of Lys because of heat damage (Pahm et al., 2008). However, based on the high Lys:CP ratios in both sources of DDGS, it appears that the production process used to produce both the DDGS-CV and DDGS-HP$_{Lincolnway}$ resulted in less heat damage compared with procedures used in the past. In particular, the Lys:CP ratio in DDGS-HP$_{Lincolnway}$ that was calculated (3.85%) is greater than any previously published values for DDGS. The reason for this observation is most likely that drying of the wet distillers grains was accomplished using very little heat and therefore Lys was not destroyed during the process. Thus, it appears that the Raymond Compression Drying System that was used to dry the DDGS-HP$_{Lincolnway}$ results in less heat damage than other drying procedures.

The Lys:CP ratios in both DDGS sources were greater than in corn, which may be attributed to the presence of residual yeast cells and yeast cell mass in DDGS (Stein and Shurson, 2009). Yeast cell mass contains significant amounts of yeast protein (~60 g/100 g DM), which has greater concentrations of AA compared with corn or DDGS, and the yeast protein contributes significantly to the protein and AA in DDGS (Belyea et al., 2004).

The concentration of starch in DDGS-CV and DDGS-HP$_{Lincolnway}$ used were 3.7% and 2.4%, respectively (Table 1). These values were lower compared with previous data (6 to 10% starch; NRC, 2012), which indicates that the fermentation process used to produce these DDGS sources was efficient in fermenting the starch in the corn. Corn and DDGS-CV contained trace amounts of glucose and fructose, whereas monosaccharides and oligosaccharides were not detected in DDGS-$HP_{Lincolnway.}$

Quantitative color measurement is one of the common practices by feed manufacturers and animal producers to evaluate the nutritional quality of DDGS (Rosentrater, 2012). Color of DDGS may vary due to differences in storage, handling, and drying conditions at the ethanol plants (Rosentrater, 2012), and also because of differences in particle size. In this experiment, DDGS-$HP_{Lincolnway}$ has greater $L^*$ (0 dark, 100 lighter) value and less $a^*$ and $b^*$ values than DDGS-CV. Data from previous research indicate that there is a relationship between DDGS color and Lys concentration because the lightest colored DDGS sources tend to have the highest Lys concentration (Cromwell et al., 1993). The particle sizes of DDGS-CV and DDGS-$HP_{Lincolnway}$ were 585 and 569 μm, respectively, and these values are in agreement with previously published data (Liu, 2008). The bulk density of DDGS-$HP_{Lincolnway}$ is 601 g/L, which is greater than that of DDGS-CV (573 g/L). Bulk density has a negative correlation with the NDF concentration of ingredients (Giger-Reverdin, 2000), and bulk density of diets may be reduced by increasing the concentration of IDF in the diet (Kyriazakis and Emmans, 2007). Thus, the greater bulk density of DDGS-$HP_{Lincolnway}$ is most likely a result of the front-end removal of fiber that is part of the process to produce DDGS-$HP_{Lincolnway}$.

The observation that the AID and SID for some AA in DDGS-$HP_{Lincolnway}$ are greater than in DDGS-CV is in agreement with reported values for DDG-HP (Widmer et al., 2007; Kim et al., 2009). The reason for this observation may be that the concentration of ADF and NDF is less in DDG-HP

**Table 4.** Apparent ileal digestibility and standardized ileal digestibility of crude protein and AA in high-protein and conventional distillers dried grains with solubles, Exp. 1[1,2]

| | AID[3] | | | | SID[3] | | | |
|---|---|---|---|---|---|---|---|---|
| Item | DDGS $HP_{Lincolnway}$[4] | DDGS-CV[4] | SEM | *P*-value | DDGS-$HP_{Lincolnway}$ | DDGS-CV | SEM | *P*-value |
| CP, % | 70.3 | 68.6 | 2.60 | 0.654 | 78.7 | 77.0 | 2.60 | 0.647 |
| Indispensable AA, % | | | | | | | | |
| Arg | 76.6 | 79.6 | 2.83 | 0.478 | 87.4 | 89.4 | 2.83 | 0.621 |
| His | 77.9 | 75.7 | 1.07 | 0.193 | 82.2 | 79.6 | 1.07 | 0.115 |
| Ile | 77.7 | 74.4 | 1.26 | 0.096 | 81.9 | 78.4 | 1.26 | 0.080 |
| Leu | 86.5 | 82.3 | 0.97 | 0.011 | 89.2 | 84.7 | 0.97 | 0.009 |
| Lys | 70.8 | 64.1 | 1.71 | 0.020 | 76.2 | 69.5 | 1.71 | 0.020 |
| Met | 85.0 | 81.3 | 1.05 | 0.031 | 87.2 | 83.3 | 1.05 | 0.026 |
| Phe | 81.9 | 78.5 | 0.97 | 0.034 | 85.5 | 81.8 | 0.97 | 0.022 |
| Thr | 67.9 | 67.2 | 0.93 | 0.619 | 75.0 | 73.7 | 0.93 | 0.363 |
| Trp | 73.2 | 73.9 | 1.44 | 0.746 | 79.5 | 80.2 | 1.44 | 0.746 |
| Val | 76.6 | 73.5 | 1.21 | 0.093 | 81.1 | 77.6 | 1.20 | 0.070 |
| Total | 79.0 | 76.3 | 1.03 | 0.086 | 83.8 | 80.7 | 1.03 | 0.059 |
| Dispensable AA, % | | | | | | | | |
| Ala | 79.1 | 76.9 | 1.42 | 0.290 | 84.5 | 81.8 | 1.42 | 0.214 |
| Asp | 66.6 | 65.7 | 1.12 | 0.600 | 72.9 | 71.8 | 1.12 | 0.504 |
| Cys | 69.7 | 68.5 | 0.88 | 0.360 | 74.9 | 73.2 | 0.88 | 0.202 |
| Glu | 84.0 | 79.7 | 1.17 | 0.026 | 87.5 | 83.1 | 1.17 | 0.024 |
| Gly | 44.0 | 52.5 | 7.70 | 0.454 | 71.2 | 77.3 | 7.70 | 0.592 |
| Ser | 75.3 | 74.8 | 0.88 | 0.682 | 81.8 | 80.9 | 0.88 | 0.468 |
| Tyr | 82.6 | 80.3 | 0.93 | 0.112 | 86.5 | 83.9 | 0.93 | 0.080 |
| Total | 75.1 | 73.4 | 1.46 | 0.435 | 82.0 | 79.9 | 1.46 | 0.346 |
| All AA | 77.1 | 74.9 | 1.19 | 0.219 | 82.9 | 80.3 | 1.19 | 0.158 |

[1]Data are least square means of 6 observations per treatment.

[2]Values for SID were calculated by correcting the values for apparent ileal digestibility for basal ileal endogenous losses. Basal ileal endogenous losses were determined (g/kg of DMI) as CP, 12.91; Arg, 0.76; His, 0.18; Ile, 0.29; Leu, 0.49; Lys, 0.34; Met, 0.06; Phe, 0.30; Thr, 0.43; Trp, 0.09; Val, 0.39; Ala, 0.61; Asp, 0.70; Cys, 0.16; Glu, 0.88; Gly, 1.81; Ser, 0.42; and Tyr, 0.23.

[3]AID = apparent ileal digestibility; SID = standardized ileal digestibility.

[4]DDGS-$HP_{Lincolnway}$ = high-protein distillers dried grains with solubles from Lincolnway Energy; DDGS-CV = conventional distillers dried grains with solubles.

**Table 5.** Apparent total tract digestibility of energy and digestible and metabolizable energy in experimental diets, Exp. 2[1]

| Item | Diet | | | SEM | $P$-value |
|---|---|---|---|---|---|
| | Corn | DDGS-HP$_{Lincolnway}$[2] | DDGS-CV[2] | | |
| GE intake, kcal/d | 7,111[b] | 7,597[a] | 7,876[a] | 145 | <0.001 |
| Fecal output, g/d | 144[c] | 224[b] | 288[a] | 16 | <0.001 |
| Fecal GE loss, kcal/d | 698[c] | 1,115[b] | 1,392[a] | 83 | <0.001 |
| Urine output, g/d | 161 | 191 | 222 | 23 | 0.067 |
| Urine GE loss, kcal/d | 7.21 | 12.31 | 8.96 | 2.1 | 0.185 |
| ATTD of GE, % | 89.81[a] | 84.85[b] | 81.70[b] | 1.1 | <0.001 |
| DE, kcal/kg | 3,319[b] | 3,479[a] | 3,422[ab] | 42 | 0.046 |
| ME, kcal/kg | 3,247 | 3,388 | 3,316 | 45 | 0.114 |

[a,b,c]Means within a row that do not have a common superscript differ, $P < 0.05$.

[1]Data are least square means of 8 observations for all treatments.

[2]DDGS-HP$_{Lincolnway}$ = high-protein distillers dried grains with solubles from Lincolnway Energy; DDGS-CV = conventional distillers dried grains with solubles.

[3]ATTD = apparent total tract digestibility.

and DDGS-HP than in DDGS-CV. High concentration of ADF and NDF usually results in reduced AID and SID of AA because of increased diet-specific endogenous losses of AA (Souffrant, 2001).

A corn basal diet was used for the energy balance experiment, and a consequence of using the difference procedure is that reliable results for the test ingredients will be obtained only if the DE and ME of the ingredient included in the basal diet are accurate. The values for the DE and ME obtained for corn in the present experiment are in close agreement with previous data (Sauvant et al., 2004; NRC, 2012), which give confidence that values for DE and ME in DDGS-HP$_{Lincolnway}$ and DDGS-CV that were calculated are also accurate.

The observation that DE and ME in DDGS-CV were not different from values obtained in corn is in agreement with previous data (Stein et al., 2006; Pedersen et al., 2007; NRC, 2012). The greater DE and ME observed in DDGS-HP$_{Lincolnway}$ on an as-fed basis compared with corn and DDGS-CV is most likely a result of greater concentrations of GE, CP, AA, and reduced concentration of insoluble fiber in DDGS-HP$_{Lincolnway}$ than in DDGS-CV. This likely also resulted in the reduced fecal and urine output from pigs fed DDGS-HP$_{Lincolnway}$ compared with pigs fed DDGS-CV, which resulted in pigs fed DDGS-HP$_{Lincolnway}$ being able to absorb and utilize more energy than pigs fed DDGS-CV.

In conclusion, the concentration of Lys and the Lys:CP ratio of DDGS-CV and DDGS-HP$_{Lincolnway}$ used in the experiment are greater compared with previously reported data indicating that these DDGS sources were less heat damaged compared with DDGS produced in the past. The DE and ME and SID of AA in corn and DDGS-CV were in agreement with published data. Values for AID and SID of most indispensable AA in DDGS-HP$_{Lincolnway}$

**Table 6.** Apparent total tract digestibility of energy and digestible and metabolizable energy in corn, high-protein distillers dried grains with solubles, and conventional distillers dried grains with solubles, Exp. 2[1]

| Item | Corn | DDGS-HP$_{Lincolnway}$[2] | DDGS-CV[2] | SEM | $P$-value |
|---|---|---|---|---|---|
| ATTD[3] of GE, % | 89.81[a] | 77.79[b] | 75.28[b] | 2.05 | 0.001 |
| As-fed basis | | | | | |
| DE, kcal/kg | 3,413[b] | 3,826[a] | 3,568[b] | 83 | 0.008 |
| ME, kcal/kg | 3,339[b] | 3,698[a] | 3,426[b] | 87 | 0.023 |
| DM basis | | | | | |
| DE, kcal/kg | 3,975[b] | 4,424[a] | 4,148[ab] | 97 | 0.013 |
| ME, kcal/kg | 3,889[b] | 4,275[a] | 3,983[ab] | 101 | 0.036 |

[a,b]Means within a row that do not have a common superscript differ, $P < 0.05$.

[1]Data are least square means of 8 observations for all treatments.

[2]DDGS-HP$_{Lincolnway}$ = high-protein distillers dried grains with solubles from Lincolnway Energy; DDGS-CV = conventional distillers dried grains with solubles.

[3]ATTD = apparent total tract digestibility.

were greater or tended to be greater than in DDGS-CV. Greater concentrations of DE and ME were also observed in DDGS-$HP_{Lincolnway}$ than in DDGS-CV, which indicates that DDGS-$HP_{Lincolnway}$ has greater nutritional value than DDGS-CV.

## LITERATURE CITED

Adeola, O. 2001. Digestion and balance techniques in pigs. In: A. J. Lewis and L. L. Southern, editors. Swine nutrition. CRC Press, Washington, DC. p. 903–916.

AOAC Int. 2007. Official methods of analysis of AOAC International. 18th ed. Rev. 2. ed. AOAC Int., Gaithersburg, MD.

Belyea, R. L., K. D. Rausch, and M. E. Tumbleson. 2004. Composition of corn and distillers dried grains with solubles from dry grind ethanol processing. Bioresour. Technol. 94:293–298. doi:10.1016/j.biortech.2004.01.001

Cervantes-Pahm, S. K., and H. H. Stein. 2010. Ileal digestibility of amino acids in conventional, fermented, and enzyme-treated soybean meal and in soy protein isolate, fish meal, and casein fed to weanling pigs. J. Anim. Sci. 88:2674–2683. doi:10.2527/jas.2009-2677

Cromwell, G. L., T. R. Cline, J. D. Crenshaw, T. D. Crenshaw, R. A. Easter, R. C. Ewan, C. R. Hamilton, G. M. Hill, A. J. Lewis, D. C. Mahan, et al. 2000. Variability among sources and laboratories in analyses of wheat middlings. NCR-42 Committee on Swine Nutrition. J. Anim. Sci. 78:2652–2658. doi:10.2527/2000.78102652x

Cromwell, G. L., K. L. Herkelman, and T. S. Stahly. 1993. Physical, chemical, and nutritional characteristics of distillers dried grains with solubles for chicks and pigs. J. Anim. Sci. 71:679–686. doi:10.2527/1993.713679x

Curry, S. M., O. J. Rojas, and H. H. Stein. 2016. Concentration of digestible and metabolizable energy and digestibility of energy and nutrients by growing pigs in distillers dried grains with solubles produced in and around Illinois. Prof. Anim. Sci. 32:687–694. doi:10.15232/pas.2016-01524

De Jong, J. A., J. M. DeRouchey, M. D. Tokach, S. S. Dritz, R. D. Goodband, C. B. Paulk, J. C. Woodworth, C. K. Jones, and C. R. Stark. 2016. Effects of wheat source and particle size in meal and pelleted diets on finishing pig growth performance, carcass characteristics, and nutrient digestibility. J. Anim. Sci. 94:3303–3311. doi:10.2527/jas.2016-0370

Erbersdobler, H. F., and A. Hupe. 1991. Determination of lysine damage and calculation of lysine bio-availability in several processed foods. Z. Ernahrungswiss. 30:46–49. doi:10.1007/bf01910731

Fastinger, N. D., and D. C. Mahan. 2006. Determination of the ileal amino acid and energy digestibilities of corn distillers dried grains with solubles using grower-finisher pigs. J. Anim. Sci. 84:1722–1728. doi:10.2527/jas.2005-308

Giger-Reverdin, S. 2000. Characterisation of feedstuffs for ruminants using some physical parameters. Anim. Feed Sci. Technol. 86:53–69. doi:10.1016/S0377-8401(00)00159-0

Jacela, J. Y., H. L. Frobose, J. M. DeRouchey, M. D. Tokach, S. S. Dritz, R. D. Goodband, and J. L. Nelssen. 2010. Amino acid digestibility and energy concentration of high-protein corn dried distillers grains and high-protein sorghum dried distillers grains with solubles for swine. J. Anim. Sci. 88:3617–3623. doi:10.2527/jas.2010-3098

Kerr, B. J., W. A. Dozier, 3rd, and G. C. Shurson. 2013. Effects of reduced-oil corn distillers dried grains with solubles composition on digestible and metabolizable energy value and prediction in growing pigs. J. Anim. Sci. 91:3231–3243. doi:10.2527/jas.2013-6252

Kim, B. G., G. I. Petersen, R. B. Hinson, G. L. Allee, and H. H. Stein. 2009. Amino acid digestibility and energy concentration in a novel source of high-protein distillers dried grains and their effects on growth performance of pigs. J. Anim. Sci. 87:4013–4021. doi:10.2527/jas.2009-2060

Kyriazakis, I., and G. C. Emmans. 2007. The voluntary feed intake of pigs given feeds based on wheat bran, dried citrus pulp and grass meal, in relation to measurements of feed bulk. Br. J. Nutr. 73:191–207. doi:10.1079/BJN19950023

Liu, K. 2008. Particle size distribution of distillers dried grains with solubles (DDGS) and relationships to compositional and color properties. Bioresour. Technol. 99:8421–8428. doi:10.1016/j.biortech.2008.02.060

NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Natl. Acad. Press, Washington, DC.

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

Pedersen, C., M. G. Boersma, and H. H. Stein. 2007. Digestibility of energy and phosphorus in ten samples of distillers dried grains with solubles fed to growing pigs. J. Anim. Sci. 85:1168–1176. doi:10.2527/jas.2006-252

Rosentrater, K. A. 2012. Distillers grains production, properties, and utilization. CRC Press, Boca Raton, FL.

Sauvant, D., J. M. Perez, and G. Tran. 2004. Tables of composition and nutritional value of feed materials: Pigs, poultry, cattle, sheep, goats, rabbits, horses, and fish. Wageningen Acad. Publ., Wageningen, The Netherlands.

Souffrant, W. B. 2001. Effect of dietary fibre on ileal digestibility and endogenous nitrogen losses in the pig. Anim. Feed Sci. Technol. 90:93–102. doi:10.1016/S0377-8401(01)00199-7

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

Stein, H. H., B. Sève, M. F. Fuller, P. J. Moughan, and C. F. M. de Lange. 2007. Invited review: Amino acid bioavailability and digestibility in pig feed ingredients: Terminology and application. J. Anim. Sci. 85:172–180. doi:10.2527/jas.2005-742

Stein, H. H., C. F. Shipley, and R. A. Easter. 1998. Technical note: A technique for inserting a T-cannula into the distal ileum of pregnant sows. J. Anim. Sci. 76:1433–1436. doi:10.2527/1998.7651433x

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

Tavárez, M. A., D. D. Boler, K. N. Bess, J. Zhao, F. Yan, A. C. Dilger, F. K. McKeith, and J. Killefer. 2011. Effect of antioxidant inclusion and oil quality on broiler performance, meat quality, and lipid oxidation. Poult. Sci. 90:922–930. doi:10.3382/ps.2010-01180

Widmer, M. R., L. M. McGinnis, and H. H. Stein. 2007. Energy, phosphorus, and amino acid digestibility of high-protein distillers dried grains and corn germ fed to growing pigs. J. Anim. Sci. 85:2994–3003. doi:10.2527/jas.2006-840