Animal Nutrition 2 (2016) 262–266

Contents lists available at ScienceDirect

Animal Nutrition

journal homepage: http://www.keaipublishing.com/en/journals/aninu/

Original Research Article

Comparative ileal amino acid digestibility of distillers' grains for growing pigs☆

Olayiwola Adeola [a, *], Darryl Ragland [b]

[a] Department of Animal Sciences, Purdue University, West Lafayette 47907, USA
[b] Department of Veterinary Clinical Sciences, Purdue University, West Lafayette 42054, USA

ARTICLE INFO

Article history:
Received 3 May 2016
Accepted 25 July 2016
Available online 3 August 2016

Keywords:
Amino acid digestibility
Distillers' dried grains
High-protein distillers' dried grains
Pigs

ABSTRACT

The objective of the experiment reported here was to investigate and compare the amino acid (AA) digestibility of distillers' dried grains (DDG), distillers' dried grains with solubles (DDGS), high protein distillers' dried grains (HP-DDG), and high protein distillers' dried grains with solubles (HP-DDGS) in growing pigs. Five semi-purified diets consisting of DDG, DDGS, HP-DDG, HP-DDGS, and nitrogen-free diet (NFD) were fed to pigs fitted with simple T-cannula for 5 observations per diet. Endogenous losses of AA at the terminal ileum of pigs that received the NFD were used to calculate standardized ileal digestibility (SID) of AA from apparent ileal digestibility (AID) of AA. The AID of Lys in DDGS was lower ($P < 0.05$) than that in DDG, which was also lower ($P < 0.05$) than that in HP-DDG. There were no differences in AID of Met among DDG, DDGS and HP-DDGS, but was greater ($P < 0.05$) in HP-DDG than in DDG or DDGS. The AID of Thr in HP-DDG was greater ($P < 0.05$) than that in DDGS but not different from that in DDG or HP-DDGS. The branched-chain AA Ile and Leu had greater ($P < 0.05$) AID in HP-DDG than in DDG, DDGS or HP-DDGS, and there was no difference among DDG, DDGS, and HP-DDGS. The AID of Trp in DDG and DDGS or HP-DDG and HP-DDGS were not different, but the AID of Trp in HP-DDGS was greater ($P < 0.05$) than that of DDGS. The greatest SID of the indispensable AA was in HP-DDG. Except for Arg and Lys in which DDG had greater ($P < 0.05$) digestibility, there was no difference between DDG and DDGS in the SID of the indispensable AA. The SID of Lys in DDG was greater ($P < 0.05$) than that of DDGS but there was no difference between that of DDG and HP-DDGS. Only His, Ile, and Met had lower ($P < 0.05$) SID in HP-DDGS than HP-DDG within the indispensable AA. The SID of Ala, Asp, Cys, Glu, Gly, Ser and Tyr were lower ($P < 0.05$) in DDGS than in HP-DDG. There SID of dispensable AA in DDG was not different from that of HP-DDGS. The current study provided apparent and standardized ileal amino acids digestibility values for traditional and high-protein corn distillers' dried grains coproducts for use in formulating swine diets. Amino acid digestibility was generally higher in HP-DDG than in other tested co-products of the dry grind processing of corn for ethanol.

1. Introduction

Corn distillers' dried grains (DDG) is a co-product of the dry grind processing of corn for ethanol production (Adeola et al., 2010; Kingsly et al., 2010). As ethanol producers implement new processes that more efficiently utilize starch from grain cereals, new co-products are being made available for use in swine feed formulation. Appropriate use of any new co-product in diets requires information on nutrient utilization and profile. Two fractionation processes have been implemented by the industry that can separate components of corn kernels to be further processed into discrete components. A back-end fractionation process takes post-fermentation DDG and separates fractions into protein and

☆ Presented in part in: Adeola, O. and D. Ragland. Ileal digestibility of amino acids in co-products of corn processing into ethanol for pigs. J. Anim. Sci. 2012; 90(Suppl. 4): 86–88.

* Corresponding author.
E-mail address: ladeola@purdue.edu (O. Adeola).

Peer review under responsibility of Chinese Association of Animal Science and Veterinary Medicine.

Production and Hosting by Elsevier on behalf of KeAi

http://dx.doi.org/10.1016/j.aninu.2016.07.008

fiber subunits. The other process is a front-end or pre-fermentation fractionation process wherein individual corn kernels are divided into 3 segments: the endosperm, the pericarp, and the germ (Zhao et al., 2010). The high-fiber fragment, the pericarp, is processed into a human food product, animal feed or biomass fuel substrate. The portion which is relatively high in oil, the germ, is segregated to extract the oil with the remainder being processed into corn germ meal. The endosperm is high in starch and protein and is the fragment used within the ethanol plant as substrate for microbes to produce ethanol. Following the fermentation process, the remaining co-product is the eventual high-protein distillers' dried grains (HP-DDG; Jacela et al., 2010). When the HP-DDG or DDG is combined with condensed distillers' solubles, the resulting product is high-protein distillers' dried grains with solubles (HP-DDGS) or distillers' dried grains with solubles (DDGS).

Because of a dearth of information on the SID and AID of amino acids (AA) in HP-DDG and HP-DDGS, the experiment reported here was conducted to investigate and compare digestibility of AA in DDG, DDGS, HP-DDG, and HP-DDGS when fed to growing pigs.

2. Materials and methods

2.1. Pigs, test ingredients, and diets

Crossbred Hampshire × Duroc × Yorkshire × Landrace barrows, obtained from the Purdue University Animal Research Farm, were used in the study. Pig surgery with simple T-cannula and animal care protocols were approved by the Purdue University Animal Care and Use Committee. The procedures were similar to those recently described by Zhai and Adeola (2011) and Cotten et al. (2016). Pigs were allowed at least 14 days to recover from surgery before initiation of the study. Average body weights of pigs at the beginning and end of the study were 50.2 kg (SD 4.5) and 54 kg (SD 5.2), respectively. Analyzed chemical composition of the test ingredients, DDG, DDGS, HP-DDG, and HP-DDGS, supplied by Mor Technology LLC (Metropolis, Illinois, USA), are presented in Table 1 and ingredient and chemical composition of the 5 diets used in the study are presented in Table 2. The nitrogen-free diet (NFD) was used to estimate basal endogenous losses of AA. Feed allowance for each pig was based on approximately 4% of body weight in 2 equal daily meals at 08:00 and 20:00. Each period lasted 7 d consisting of 5 d for the pigs to adapt to the experimental diets, followed by a 2 d collection period of ileal digesta during which a plastic tubular bag was attached to the externalized T-cannula on d 6 and 7. To reduce proliferation of bacteria in the ileal samples, each bag contained 10 mL of 5% formic acid, and ileal contents were stored at −20°C between collections. Chromic oxide was added as an indigestible marker calculation of ileal nutrient digestibility by the index method.

2.2. Analyses

Diets and freeze-dried ileal digesta were ground through a 0.5-mm screen prior to analyses. Samples were dried at 100°C for 24 h to determine the dry matter (AOAC, 2006). Chromium (Cr) concentration was determined by the inductively coupled plasma atomic emission spectroscopy method following wet ash digestion with nitric and perchloric acid. Nitrogen (N; AOAC, 2006) was determined by the combustion method (model FP2000, LECO Corp., St. Joseph, MI, USA) using EDTA as a standard. Analyses of AA (AOAC, 2006) were conducted at the Experimental Station Chemical Laboratory, University of Missouri, Columbia, MO, USA. Sample hydrolysis used 6 mol/L HCl at 100°C for 24 h under N atmosphere. For the sulfur AA (Met and Cys), performic acid oxidation occurred prior to acid hydrolysis. Barium hydroxide was used to hydrolyze tryptophan during analysis. High pressure liquid chromatography (HPLC) after post-column derivatization was used to determine AA concentrations in hydrolyzate.

The apparent ileal digestibility (AID) of AA was calculated as: AID (%) = 100 × [1 − (Cr in diet/Cr in digesta) × (AA in digesta/AA in diet)]; Ileal endogenous loss (IEL) of AA in mg AA per kg of dry matter intake (DMI) was calculated as: AA in ileal digesta (mg/kg) × [Cr in diet (mg/kg)/Cr in digesta (mg/kg)]; standardized ileal digestibility (SID) of AA was calculated as: SID (%) = AID (%) + [(IEL/AA in diet) × 100]. Data was analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC, USA) for a Latin square design, with pig serving as the experimental unit. The model included the fixed effects of the diet, with block, period, and pig as random effects. The LSMEANS statement in SAS was used to generate means, which were separated using the possible difference option in SAS and a probability level of 5% was considered significant.

Table 1
Analyzed dry matter, nitrogen (N), and amino acid (AA) composition of distillers' dried grains (DDG), distillers' dried grains with solubles (DDGS), high protein distillers' dried grains (HP-DDG) and high protein distillers' dried grains with solubles (HP-DDGS) on an as-fed basis.

Item	DDG	DDGS	HP-DDG	HP-DDGS
Dry matter, g/kg	936.3	888.4	961.5	878.1
Crude protein (N × 6.25), g/kg	315	277	579	481
Crude fat, g/kg	89	11	19	27
Crude fiber, g/kg	91	74	47	36
Neutral detergent fiber, g/kg	496	371	417	279
Acid detergent fiber, g/kg	179	108	263	160
Ca, g/kg	0.2	2.0	0.2	0.5
Total P, g/kg	4.8	7.7	1.8	2.5
Indispensable AA, g/kg				
Arg	12.9	13.5	18.4	15.5
His	8.8	8.5	15.4	13.7
Ile	12.9	10.6	24.0	19.2
Leu	43.6	32.7	89.6	67.5
Lys	9.3	10.5	9.8	10.6
Met	6.7	5.4	13.9	9.8
Phe	17.2	13.1	34.6	24.7
Thr	11.6	10.3	20.1	16.8
Trp	2.0	2.1	2.8	2.5
Val	17.2	15.1	28.8	25.0
Dispensable AA, g/kg				
Ala	25.0	20.5	48.9	39.1
Asp	20.1	17.6	34.8	26.2
Cys	6.0	5.2	10.9	8.1
Glu	52.2	37.9	105.0	64.4
Gly	11.7	11.7	17.7	15.2
Pro	25.7	20.4	52.4	37.0
Ser	13.2	11.5	24.0	19.9
Tyr	13.1	9.9	27.6	19.3

3. Results

Table 3 shows the comparative AID of AA in DDG, DDGS, HP-DDG, and HP-DDGS. The AID of Lys in DDGS was lower ($P < 0.05$) than that in DDG, which was also lower ($P < 0.05$) than that in HP-DDG. There were neither differences in AID of Lys between HP-DDGS and DDGS nor between HP-DDGS and DDG. Other cationic AA, Arg and His, followed similar trends as Lys relative to differences among ingredients but the digestibility of those AA were much greater than that of Lys (Table 3). The AID of Met was not different among DDG, DDGS and HP-DDGS, but was greater ($P < 0.05$) in HP-DDG than in DDG or DDGS. The AID of Thr in HP-DDG was greater ($P < 0.05$) than that in DDGS but not different from that in DDG or HP-DDGS. The branched-chain AA, Ile and Leu, had greater ($P < 0.05$) AID in HP-DDG than DDG, DDGS or HP-DDGS, and there was no difference among DDG, DDGS, and HP-DDGS. The AID

Table 2
Ingredient and analyzed composition of experimental diets of distillers' dried grains (DDG), distillers' dried grains with solubles (DDGS), high protein distillers' dried grains (HP-DDG), high protein distillers' dried grains with solubles (HP-DDGS), and nitrogen-free diet (NFD) on an as-fed basis.

Item	DDG	DDGS	HP-DDG	HP-DDGS	NFD
Ingredients, g/kg					
DDG	564.5	0	0	0	0
DDGS	0	505.5	0	0	0
HP-DDG	0	0	242	0	0
HP-DDGS	0	0	0	329.9	0
Corn starch	254.5	313.5	527	462.6	769.5
Dextrose	100	100	150	165.5	100
Soy oil	30	30	30	30	30
Marker premix[1]	25	25	25	25	25
Monocalcium phosphate	8.5	8.5	8.5	8.5	20
Limestone	12	12	12	12	5
Solka-floc[2]	0	0	0	0	40
NaCl	3	3	3	3	3
Vitamin premix[3]	1.5	1.5	1.5	1.5	1.5
Mineral premix[4]	1	1	1	1	1
Potassium carbonate	0	0	0	0	4
Magnesium oxide	0	0	0	0	1
Total	1,000	1,000	1,000	1,000	1,000
Analyzed composition, g/kg					
Dry matter	876.0	864.2	869.3	871.4	858.3
Crude protein (N × 6.25)	177.4	141.8	135.8	157.5	10.1
Indispensable AA, g/kg					
Arg	7.6	6.6	3.8	5.2	0.1
His	4.7	3.9	3.1	4.1	0.1
Ile	7.1	5.4	5.5	6.4	0.2
Leu	24.8	16.6	20.3	22.7	0.4
Lys	5.2	5.1	2.1	3.4	0.2
Met	3.9	2.6	3.2	3.5	0.1
Phe	9.6	6.7	7.9	8.2	0.2
Thr	7.2	5.3	4.5	5.6	0.2
Trp	1.3	1.3	1.3	1.0	<0.4
Val	9.4	7.2	6.5	8.0	0.2
Dispensable AA, g/kg					
Ala	14.1	10.5	11.1	13.5	0.3
Asp	11.6	9.1	8.0	9.5	0.3
Cys	3.4	2.4	2.3	2.8	0.1
Glu	32.4	22.3	26.7	30.1	0.6
Gly	6.9	6.2	4.1	5.6	0.1
Pro	16.0	10.9	12.5	14.5	0.0
Ser	8.3	6.0	6.2	6.6	0.1
Tyr	7.2	4.8	5.1	5.6	0.1

[1] Contained 20 g cornstarch and 5 g chromic oxide.
[2] Purified cellulose.
[3] Vitamin premix supplied per kilogram of diet: vitamin A, 2,423 IU; vitamin D_3, 242 IU; vitamin E, 17.6 IU; vitamin K activity, 2.4 mg; menadione, 804 µg; vitamin B_{12}, 14.1 µg; riboflavin, 2.8 mg; D-pantothenic acid, 9 mg; niacin, 13 mg.
[4] Mineral premix supplied per kilogram of diet: Cu (as copper sulfate), 9 mg; I (as calcium iodate), 0.34 mg; Fe (as ferrous sulfate), 97 mg; Mn (as manganese oxide), 12 mg; and Zn (as zinc oxide), 97 mg.

Table 3
Apparent ileal digestibility (%) of amino acids (AA) in distillers' dried grains (DDG), distillers' dried grains with solubles (DDGS), high protein distillers' dried grains (HP-DDG) and high protein distillers' dried grains with solubles (HP-DDGS).

Item	DDG	DDGS	HP-DDG	HP-DDGS	SEM
Number of observations	5	5	5	5	
Indispensable AA, %					
Arg	89.6^{b}	86.2^{c}	92.6^{a}	87.2^{bc}	0.9
His	87.9^{b}	85.5^{b}	92.0^{a}	87.5^{b}	1.2
Ile	87.6^{b}	85.7^{b}	92.1^{a}	88.3^{b}	1.1
Leu	91.6^{b}	90.0^{b}	94.8^{a}	92.0^{b}	0.8
Lys	78.1^{b}	70.2^{c}	87.1^{a}	72.0^{bc}	2.5
Met	91.6^{b}	90.6^{b}	94.9^{a}	92.4^{bc}	0.7
Phe	89.8^{b}	87.5^{b}	93.1^{a}	90.4^{ab}	0.9
Thr	84.5^{ab}	80.5^{b}	88.4^{a}	84.5^{ab}	1.5
Trp	89.3^{ab}	86.2^{b}	90.0^{ab}	90.5^{a}	1.3
Val	86.6^{b}	83.7^{b}	91.1^{a}	87.2^{ab}	1.3
Dispensable AA, %					
Ala	90.4^{ab}	87.7^{b}	93.4^{a}	90.3^{ab}	1.0
Asp	85.0^{ab}	79.8^{b}	88.5^{a}	84.3^{ab}	1.7
Cys	87.2^{ab}	83.0^{b}	90.3^{a}	86.0^{ab}	1.5
Glu	91.0^{ab}	88.8^{b}	94.0^{a}	90.9^{ab}	1.0
Gly	83.6^{a}	73.7^{b}	86.2^{a}	78.8^{bc}	2.2
Pro	89.3^{a}	79.5^{c}	88.9^{ab}	81.0^{bc}	2.6
Ser	88.6^{a}	84.8^{b}	90.6^{a}	88.5^{ab}	1.2
Tyr	90.4^{b}	88.4^{b}	93.4^{a}	90.5^{bc}	0.9

[a,b,c] Means in a row with common superscripts are not different at $P < 0.05$.

Table 4
Endogenous losses of amino acids (AA) at the terminal ileum on a dry matter intake (DMI) basis.

Item	Endogenous loss, mg/kg DMI	SEM
Indispensable AA		
Arg	456	17
His	167	12
Ile	274	34
Leu	489	74
Lys	426	61
Met	82	15
Phe	285	38
Thr	512	58
Trp	89	8
Val	419	47
Dispensable AA		
Ala	515	47
Asp	681	64
Cys	136	13
Glu	877	103
Gly	1,122	150
Pro	3,390	615
Ser	475	42
Tyr	228	31

of Val in HP-DDG was greater ($P < 0.05$) than that in DDG or DDGS but not different from that in HP-DDGS. There was no difference between the AID of Trp in DDG and DDGS as well as between the AID of Trp in HP-DDG and HP-DDGS, but the AID of Trp in HP-DDGS was greater ($P < 0.05$) than that of DDGS. The AID of dispensable AA generally greater ($P < 0.05$) in HP-DDG than the other distillers' dried grains co-products investigated (Table 3).

Endogenous losses of AA at the terminal ileum of pigs that received the nitrogen-free diet are presented in Table 4. Proline, Gly, and Glu were the most abundant and highly variable of the endogenous AA flow in the terminal ileum. The HP-DDG had the greatest SID of the indispensable AA (Table 5). Except for Arg and Lys in which DDG had greater digestibility, DDG and DDGS did not differ in SID of other indispensable AA. The SID of Lys in DDG was greater ($P < 0.05$) than that of DDGS, but there was no difference between that of DDG and HP-DDGS. Of the indispensable AA, only His, Ile, and Met had lower ($P < 0.05$) SID in HP-DDGS than HP-DDG, there was no difference in the SID of the remaining AA. The SID of the dispensable AA listed in Table 5 were not different between HP-DDG and HP-DDGS, although HP-DDG was numerically greater. The SID of Pro in DDGS was not different from that of HP-DDG. However, the SID of Ala, Asp, Cys, Glu, Gly, Ser and Tyr were lower ($P < 0.05$) in DDGS than in HP-DDG. The SID of dispensable AA in DDG was not different from that of HP-DDGS (Table 5).

4. Discussion

Appropriate use of any new co-product in swine diets requires information on nutrient profile and utilization. The current experiment was conducted to contribute to the sparse pool of knowledge on the SID of AA in HP-DDG and HP-DDGS for pigs and compare digestibility of AA in DDG, DDGS, HP-DDG, and HP-DDGS. The crude protein and AA composition of the DDG used in the current study

Table 5
Standardized ileal digestibility (%) of amino acids (AA) in distillers' dried grains (DDG), distillers' dried grains with solubles (DDGS), high protein distillers' dried grains (HP-DDG) and high protein distillers' dried grains with solubles (HP-DDGS).

Item	DDG	DDGS	HP-DDG	HP-DDGS	SEM
Number of observations	5	5	5	5	
Indispensable AA, %					
Arg	96.8[a]	93.1[b]	98.6[a]	96.0[ab]	1.0
His	91.7[b]	89.1[b]	95.3[a]	91.7[b]	1.2
Ile	91.6[b]	89.6[b]	95.9[a]	92.4[b]	1.1
Leu	93.7[b]	92.0[b]	96.9[a]	94.1[ab]	0.9
Lys	88.6[ab]	79.9[c]	94.6[a]	85.8[bc]	2.5
Met	93.9[b]	92.8[b]	97.1[a]	94.6[b]	0.6
Phe	93.0[b]	90.7[b]	96.2[a]	93.6[ab]	1.0
Thr	92.5[ab]	88.4[b]	95.7[a]	93.5[a]	1.6
Trp	95.4[ab]	92.6[b]	97.0[a]	97.0[a]	1.3
Val	91.4[ab]	88.4[b]	95.5[a]	92.3[ab]	1.4
Dispensable AA, %					
Ala	94.1[ab]	91.4[b]	96.9[a]	94.1[ab]	1.0
Asp	91.3[ab]	86.0[b]	94.3[a]	91.2[ab]	1.7
Cys	91.7[ab]	87.3[b]	94.5[a]	90.8[ab]	1.5
Glu	93.9[ab]	91.6[b]	96.8[a]	93.7[ab]	1.0
Gly	101.3[a]	90.7[b]	101.1[a]	99.2[a]	2.6
Pro	112.0[a]	101.8[b]	110.6[ab]	103.9[ab]	2.9
Ser	94.8[ab]	91.0[b]	96.7[a]	95.1[a]	1.3
Tyr	93.9[b]	91.9[b]	96.9[a]	94.2[ab]	0.9

[a,b,c] Means in a row with common superscripts are not different at $P < 0.05$.

are similar to those reported by Applegate et al. (2009) and Kim et al. (2011) but higher than reported by Pahm et al. (2008) and summarized in NRC (2012). The DDGS used in the current study has similar crude protein and AA composition to those previously reported (Adedokun et al., 2008; Stein and Shurson. 2009; NRC, 2012). The crude protein and AA concentration of DDG used in this study is greater than DDGS. During dry-grind ethanol processing, DDGS is obtained by drying two products streams, namely the wet distillers' grains and the condensed distillers' solubles in a ratio that varies from plant to plant and thus dilutes the DDG. Furthermore, fractionation process results in HP-DDG and HP-DDGS containing more crude protein and AA than the DDG and DDGS. New processes that more efficiently utilize starch from grain cereals in the dry grind processing of corn for ethanol production result in new feed co-products. Back-end (post-fermentation) or front-end fractionation process separates components into protein, oil, and fiber subunits and produces a high-protein co-products HPDDG or HPDDGS (Zhao et al., 2010). Predictably, the AA concentrations of HPDDG or HPDDGS are considerably higher than those of DDG or DDGS; and higher in DDG or HPDDG than in DDGS or HPDDGS because no solubles are added back to the DDG or HPDDG as is the case for DDGS or HPDDGS. The analyzed crude protein of the HP-DDG used in this study is greater than the reported CP for HP-DDG of 408 g/kg by Jacela et al. (2010), 456 g/kg by Jung and Batal (2009) and 534 g/kg by Applegate et al. (2009). The variations seen in these values could be due to processing differences in the ethanol facilities that supplied the HP-DDG. The HP-DDG used in Jung and Batal (2009) study was from back-end fractionation process whereas Applegate et al. (2009) study used HP-DDG derived from front-end fractionation; the type of fractionation for the other studies was not reported.

In previous studies (Zhai and Adeola, 2011; Xue et al., 2014) with 30-kg, 40-kg, and 60-kg pigs, basal endogenous ileal losses of lysine between 430 and 490 mg/kg DMI were reported compared with 426 mg/kg DMI in the current study. Correction of ileal AA output for basal endogenous losses of AA is pivotal to deriving SID from AID of AA. Proline (3,390 mg/kg DMI) and Gly (1,122 mg/kg DMI) were the two most abundant endogenous AA in endogenous flow and together accounted for approximately 42% of the total endogenous AA flow. The least abundant AA in endogenous AA flow were Met and Trp (89 mg/kg DMI), which together accounted for less than 2% of the total endogenous AA flow. In quantitative terms, basal endogenous AA loss is a primary component of maintenance requirement for AA and the AA composition of basal ileal endogenous CP is instructive. Jansman et al. (2002), in a review of literature data reported that AA account for 81% of the basal ileal endogenous protein, which is similar to 80% obtained in the current study.

Addition of condensed distillers' solubles to distillers' grains reduced the AID and SID of Lys regardless of whether it is the traditional or high-protein type. The lowest SID in co-products of corn processing into ethanol was for Lys. Some of the Lys may have been damaged by the heat applied to the product during dehydration process following the addition of condensed distillers' solubles. Heat damage through Maillard reaction has been shown to reduce both the concentration and the digestibility of Lys (Pahm et al., 2008). Reports of digestibility of AA in DDGS abound in the literature. The AID and SID of AA in DDGS in the current study are generally greater than those reported by Stein et al. (2006) and Urriola et al. (2009). Unlike Lys and Arg, whose epsilon amino group could react with reducing sugars following heat application, the AID and SID of most of the indispensable AA were not different between DDG and DDGS presumably due to use of steam in drying instead of direct heat, which may have minimized the Maillard reaction, and the absence of solubles in the final product. Furthermore, the AID and SID of most of the dispensable AA, except Gly and Pro, were not different. Unlike the DDGS, there is a dearth of information on digestibility of AA in high-protein co-product for pigs. In a study conducted to determine AA digestibility of HP-DDG from corn, Jacela et al. (2010) reported AID and SID of Lys that are much lower than observed in the current study. The SID of the indispensable AA Ile, Lys, Met, and Thr, and the dispensable AA Tyr in HP-DDG were higher than those of DDGS. The high-protein co-products of corn processing into ethanol used in the current study were derived from de-hulling and de-germing the corn before the fermentation process. Removal of much of the fiber and oil prior to fermentation changes composition of HP-DDG compared with the DDG. The SID for most AA in HP-DDG and HP-DDGS determined in this experiment are greater than the average values reported in NRC (2012) or values reported for HP-DDG in Jacela et al. (2010).

5. Conclusions

The current study provided apparent and standardized ileal digestibility values for traditional and high-protein corn distillers' dried grains coproducts for use in formulating swine diets. Additionally, digestibility of AA in the high-protein co-products of corn processing into ethanol is between 2 and 8 percentage units more than that of the conventional counterparts.

Acknowledgements

The authors gratefully acknowledge Anna Goad, Pat Jaynes, and Dr. Oluyinka Olukosi for their varied roles in the conduct of this study.

References

Adedokun SA, Adeola O, Parsons CM, Lilburn MS, Applegate TJ. Standardized ileal amino acid digestibility of plant feedstuffs in broiler chickens and turkey poults using a nitrogen-free or casein diet. Poult Sci 2008;87:2535–48.
Adeola O, Jendza JA, Southern LL, Powell S, Owusu-Asiedu A. Contribution of exogenous dietary carbohydrases to the metabolizable energy value of corn distillers grains for boiler chickens. Poult Sci 2010;89:1947–54.
AOAC. Int.. Official methods of analysis. 18th ed. Arlington, VA: Assoc. Offic. Anal. Chem.; 2006.

Applegate TJ, Troche C, Jiang Z, Johnson T. The nutritional value of high-protein corn distillers dried grains for broiler chickens and its effect on nutrient excretion. Poult Sci 2009;88:354–9.
Cotten B, Ragland D, Thomson JE, Adeola O. Amino acid digestibility of plant protein feed ingredients for growing pigs. J Anim Sci 2016;94:1073–82.
Jacela JY, Frobose HL, DeRouchey JM, Tokach MD, Dritz SS, Goodband RD, et al. 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 2010;88:3617–23.
Jansman AJM, Smink W, van Leeuwen P, Rademacher M. Evaluation through literature data of the amount and amino acid composition of basal endogenous crude protein at the terminal ileum of pigs. Anim Feed Sci Technol 2002;98:49–60.
Jung B, Batal A. The nutrient digestibility of high-protein corn distillers dried grains and the effect of feeding various levels on the performance of laying hens. J Appl Poult Res 2009;18:741–51.
Kim EJ, Utterback PL, Applegate TJ, Parsons CM. Comparison of amino acid digestibility of feedstuffs determined with the precision-fed cecectomized rooster assay and the standardized ileal amino acid digestibility assay. Poult Sci 2011;90:2511–9.
Kingsly ARP, Ileleji KE, Clementson CL, Garcia A, Maier DE, Stroshine RL, et al. The effect of process variables during dying on the physical and chemical characteristics of corn dried distillers grains with solubles (DDGS) – plant scale experiment. Bioresour Technol 2010;101:193–9.
NRC. Nutrient requirements of swine. 11th rev. ed. Washington, DC: Natl. Acad. Press; 2012.
Pahm AA, Pedersen C, Hoehler D, Stein HH. Factors affecting the variability in ileal amino acid digestibility in corn distillers dried grains with solubles fed to growing pigs. J Anim Sci 2008;86:2180–9.
Stein HH, Gibson ML, Pedersen C, Boersma MG. Amino acid and energy digestibility in ten samples of distillers' dried grain with solubles fed to growing pigs. J Anim Sci 2006;84:853–60.
Stein HH, Shurson GC. BOARD-INVITED REVIEW: the use and application of distillers dried grains with solubles in swine diets. J Anim Sci 2009;87:1292–303.
Urriola PE, Hoehler D, Pedersen C, Stein HH, Shurson GC. Amino acid digestibility of distillers dried grains with solubles, produced from sorghum, a sorghum-corn blend, and corn fed to growing pigs. J Anim Sci 2009;87:2574–80.
Xue PC, Ragland D, Adeola O. Determination of additivity of apparent and standardized ileal digestibility of amino acids in diets containing multiple protein sources fed to growing pigs. J Anim Sci 2014;92:3937–44.
Zhao R, Wu X, Bean S, Wang D. Ethanol from grain crops. In: Singh BP, editor. Industrial crops and uses. Cambridge, MA, USA: CABI International; 2010. p. 84–101.
Zhai H, Adeola O. Apparent and standardized ileal digestibilities of amino acids for pigs fed corn-soybean meal-based diets at varying crude protein levels. J Anim Sci 2011;89:3626–33.