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Determination of apparent and standardized ileal digestibility of amino acids in corn HP-DDG fed to growing pigs

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The corn-based ethanol production industry provides co-products with potential value as animal feed. However, the nutritional value of these co-products should be adequately determined for their sustainable implementation in swine diets. Therefore, a study was conducted to determine the concentration of amino acids (AA), apparent ileal digestible amino acids (AID), standardized ileal digestible amino acids (SID), and crude protein (CP) in corn distillers dried grains with high protein content (corn HP-DDG) for pigs. Six growing pigs (initial body weight: 46.30 ± 2.14 kg) were surgically fitted with a T-cannula at the distal ileum and allotted to a duplicate 2 × 3 incomplete Latin Square Design. Diets containing corn HP-DDG as the only AA source and a nitrogen-free diet (NFD) were formulated. Corn HP-DDG was used as a test ingredient to replace 40% of the starch in NFD, and titanium dioxide (0.5%) was added as an indigestible marker to both diets. Pigs were fed between 08:00 and 18:00 h during five days of adaptation and a sequence of two days of ileal digesta collection. On an as-fed basis, the chemical composition of corn HP-DDG was 40.41% CP, 1.39% lysine, 1.57% methionine + cysteine, 1.61% threonine, 0.23% tryptophan, and 2.15% valine. The AID and SID values of corn HP-DDG were 74.04% and 80.87% for CP; 76.32% and 79.15% for lysine; 84.75% and 86.52% for methionine + cysteine; 71.97% and 78.30% for threonine; 83.86% and 92.44% for tryptophan; and 76.34% and 80.47% for valine, respectively. In conclusion, the SID CP and AA in corn HP-DDG were within the previously published values, and the determined SID coefficients should be used to formulate accurate diets for pigs.

KEYWORDS

HP-DDG, amino acids digestibility, corn, co-products, swine, pigs

1 Introduction

For decades, the modern swine industry has operated at a narrow net profit margin as pig production costs have frequently increased to a greater than the price of live pigs/pork meat. Consequently, the pork meat industry has put efforts into developing innovative solutions to improve the economic efficiency of intensive pig rearing without compromising pork meat quality, animal welfare, and sustainability. The utilization of alternative feed ingredients in practical feeds, such as co-products from other industries (e.g., food, alcohol production, etc.), contributes to providing nutrients and for more ecologically responsible practices in pork production.

Among the several co-products that could be used in pig feeds, those from the ethanol industry are especially notable. The fermentation of corn starch produces a variety of co-products, such as dry distiller grains (DDG), DDG with solubles (DDGS), and high-protein DDG (HP-DDG), which differ from each other with regards to the concentrations of protein, fiber, fat, and minerals (Stein and Shurson, 2009; Woyengo et al., 2014). Including the referred co-products in swine diets has been shown to support adequate performance and reduce food costs (Zijlstra and Beltranena, 2022). Nonetheless, there is variation in the nutritional composition of these co-products due to the nature of the raw materials and technologies utilized during their manufacturing processes (Liu, 2011; Rho et al., 2017).

Recently, fiber separation technology (FST; ICM, Inc., Colwich, Kansas, USA) has been implemented in some ethanol production facilities in Brazil, creating a specific corn co-product. FST removes fiber from the grain before corn starch fermentation into ethanol (Paula et al., 2021), increasing the amount of fermentable starch in the fermenters and thus enhancing ethanol production capacity and yield. This approach allows the production of high-protein corn DDG (HP-DDG), which has a crude protein content of approximately 40% (Shurson, 2018; Paula et al., 2021). Additionally, it increases the lipid content, and reduces neutral detergent fiber content (Paula et al., 2021).

Knowledge of the concentration and digestibility of amino acids in ingredients is essential to optimize the economic and environmental efficiency with which nitrogen is manipulated in pig feeds. Based on the innovative nature of the co-products from the ethanol industry investigated in the current study and the advantages of their utilization in practical pig feeding, we believe that it is opportune to investigate their nutritional value for pigs. Such data, whether compiled with published literature, could contribute to updates of existing feeding tables, such as the National Research Council (2012) and Rostagno et al. (2017). Therefore, the objective of this study was to determine the values of apparent ileal digestible amino acids (AID) and standardized ileal digestible amino acids (SID) and digestible crude protein (CP) from corn HP-DDG from Brazil, produced using FST technology in growing pigs.

2 Materials and methods

All procedures adopted in this study were approved by the Ethics Committee for the Use of Production Animals at the Federal University of Viçosa (protocol number 59/2023) and followed the National Council for Experimentation Animal Control norms.

2.1 Animal housing, diets, and experimental design

The experiment was conducted at the Unit of Teaching, Research, and Extension in Pig Improvement of the Department of Animal Science at the Universidade Federal de Viçosa. This study aimed to determine the AID and SID of CP and amino acids in corn HP-DDG using the ileal digestibility technique, with the determination of basal endogenous losses.

Before the experiment, six growing barrows were surgically fitted with a simple T-cannula at the distal ileum 20 cm from the ileocecal valve, using a technique adapted from Donkoh et al. (1994). The animals were fasted for 12 h before the procedure to minimize digesta contamination during the operation. Subsequently, the animals were anesthetized, placed in the left lateral decubitus position, and extensively shaved to ensure asepsis at the surgical site. A vertical 5 cm–6 cm incision was made in the flank region, positioned 3 cm–4 cm from the caudal vertebra to the last rib. The small intestine was then excised and manipulated. An incision of 2 cm–2.5 cm was made along the antimesenteric side of the small intestine, 10 cm–15 cm from the cranial segment to the ileocecal junction. A suture was placed around the incision and a cannula was inserted and fixed to the intestine. A 1-cm diameter skin incision was made from 3 cm to 4 cm dorsal to the initial incision. Subsequently, all the tissues were sutured.

Pigs were individually housed in 2.3 m × 2.16 m × 0.95 m (length × width × height) pens equipped with a trough feeder and a nipple waterer without any bedding material. The room was washed and disinfected using quicklime, water, and a disinfectant solution.

During the five days following the surgical procedure, the animals received therapeutic antibiotics as a prophylactic measure. During the postoperative period, feed was gradually reintroduced to the animals and provided *ad libitum*. The transition diet was formulated using corn and soybean meal to meet all nutritional requirements (Table 1) as described by Rostagno et al. (2017). The skin suture was removed 15 days after the surgery.

The ileal digestibility test with a simple T-cannula was performed 15 days after the surgery, considering the recovery of all animals. Six barrows (initial body weight: 46.30 kg ± 2.14 kg) were allotted to a duplicate 2 × 3 incomplete Latin Square Design, with two diets and two 7-d periods in each square, totaling six observations per treatment. In the second period, the animals were changed to exclude the effects of the individual on the measured

TABLE 1 Calculated composition and nutrients in transition diet.

Ingredients	%
Corn, 7.88% CP	61.85
Soybean meal, 45% CP	31.73
Soybean oil	1.47
Vitamin Supplement[1]	0.30
Mineral Supplement premix[2]	0.25
Antioxidant[3]	0.01
Dicalcium phosphate	1.91
Limestone	0.86
Salt	0.48
Lysine-HCL	0.45
DL-Methionine	0.18
L-Threonine	0.21
L-Tryptophan	0.03
L-valine	0.07
Inert	0.20
Total	100.00
Nutrients	
ME, kcal/kg	3,256.50
Crude Protein, %	20.03
SID Lysine, %	1.26
SID Methionine + Cysteine, %	0.76
SID Threonine, %	0.86
SID Tryptophan, %	0.25
Available Phosphorus, %	0.45
Calcium, %	0.91
Sodium, %	0.20

[1]Provided the following quantities per kilogram of complete diet: Se as sodium selenite and selenium yeast, 75.0 mg/kg; vitamin A as retinyl acetate, 2,000 IU/kg; vitamin D3 as cholecalciferol, 375,000 IU/kg; vitamin E as DL-alpha tocopherol, 6,250 UI/kg; vitamin K3 as menadione nicotinamide bisulfate 750.0 mg/kg; thiamin as thiamine mononitrate, 500.0 mg/kg; riboflavin, 1,500 mg/kg; pyridoxine as pyridoxine hydrochloride, 500.0 mg/kg; vitamin B12, 7,500.00 mcg/kg; folic acid, 250.0 mg/kg; pantothenic acid as D-calcium pantothenate, 5,000.00 mg/kg; niacin, 8,750.00 mg/kg; biotin, 37.50 mg/kg.
[2]Provided the following quantities per kilogram of complete diet: Fe, 15.00 g/kg as iron sulfate, Cu, 40 g/kg as copper sulfate, Mn, 13g/kg as manganese monoxide; Zn, 25 g/kg as zinc sulfate; I, 350.00 mg/kg as calcium iodate.
[3]Bannox antioxidant.

food digestibility. The corn HP-DDG source was obtained from FS Bioenergy (Lucas do Rio Verde, Mato Grosso, Brazil), and was characterized as a co-product of corn obtained from ethanol production using FTS technology, with an average composition of 43.85% crude protein, 11.17% ether extract, 7.09% crude fiber, and 2.17% mineral matter concentration (Table 2). A nitrogen-free diet (NFD) was formulated to measure the basal endogenous losses of CP and AA. The test diet was prepared by replacing 40% cornstarch with corn HP-DDG as the sole AA source. Vitamins and minerals were included in all diets to meet or exceed the estimated requirements according to Rostagno et al. (2017). Titanium dioxide (TiO2) was included in both diets at 0.5%, as an indigestible marker (Table 3). Chemical and analysis of the composition of experimental diets are presented in Table 4.

2.2 Experimental procedure

Pigs were fed twice daily (at 0700 and 1700 h) based on their metabolic weight ($BW^{0.75}$, kg), with the feed mixed with water in a 1:1 ratio to avoid waste and facilitate intake. Throughout the experiment, pigs had free access to water. The first five days of each period were considered an adaptation period to the diet. On days 6 and 7 of each period, ileal digesta samples were collected over 10 h.

The ileal digesta was collected using plastic bags (5 cm × 20 cm) attached directly to the cannula using a cable tie. Digesta flowing into the bags was collected and immediately stored under −20°C to prevent bacterial degradation of amino acids. New bags were then attached to the cannula to continue collection.

During the 5-d period between ileal digesta collections, the animals were fed a corn and soybean meal-based diet (Table 1) to meet the requirements describe d by Rostagno et al. (2017). Water was provided *ad libitum* throughout the study.

During the second collection period, one animal subjected to DIP treatment presented with rectal prolapse and was removed from the evaluation by a specialist.

2.3 Processing of collected material and analysis

At the end of the experimental period, ileal digesta samples were thawed, mixed, homogenized, and lyophilized by the experimental unit and period. A subsample was collected for analysis, with six repetitions per treatment.

Samples of the diets, corn HP-DDG, and ileal digesta were analyzed to determine dry matter (DM), nitrogen (N), TiO2, and AAs. The methodologies used were as follows: the INCT-CA G-003/1 method for DM content, the Kjeldahl method for N content, and the INCT-CA method M-007/1 for TiO2 concentration, as described by Detmann et al. (2012). The analyses were conducted at the Laboratory of Animal Nutrition of the Department of Animal Science, Federal University of Viçosa, Mato Grosso, Brazil. Additionally, high-pressure liquid chromatography (HPLC) for AA content was conducted at the CBO Laboratory (Valinhos, São Paulo, Brazil), according to the methods described by White et al. (1986), Hagen et al. (1989), and Lucas and Sotelo (1980).

The factor 6.25 was used to calculate crude protein based on the N content.

2.4 Calculations

The AID and SID of CP and AA of corn HP-DDG were calculated for the diet containing corn HP-DDG using a direct procedure. The values calculated for this diet represented the values of the test ingredients. The following formulas were used to determine the AID and SID coefficients (Sakomura and Rostagno, 2016):

FI1 = Test diet indigestibility factor

$$FI1 = \frac{\%\ TiO2\ \ test\ \ diet}{\%\ \ TiO2\ \ test\ \ digesta}$$

Apparent ileal digestibility coefficient of crude protein (AID CP):

$$AID\ \ CP(\%) = \frac{[(\%\ \ CP\ \ in\ \ diet - (\%\ \ CP\ \ in\ \ digesta\ \ \times FI1))]}{\%\ \ CP\ \ in\ \ diet} \times 100$$

FI2 = NFD indigestibility factor

Standardized ileal digestibility coefficient of crude protein (SID CP)

$$SID\ \ CP(\%) = \frac{[(\%\ \ CP\ \ in\ \ diet - (\%\ \ CP\ \ in\ \ digesta\ \ \times FI1) - (\%\ \ CP\ \ in\ \ digesta\ \times\ FI2))]}{\%\ \ CP\ \ in\ \ diet} \times 100$$

E1 = Digesta of test diet

Apparent ileal digestibility coefficient of amino acids (AID AA)

$$AID\ \ AA(\%) = \frac{[(mg\ \ AA/g\ \ diet - (mg\ \ AA/g\ \ E1 \times FI1)]}{mg\ \ AA/g\ \ in\ \ diet} \times 100$$

E2 = Digesta of NFD

Standardized ileal digestibility coefficient of amino acids (SID AA)

$$SID\ \ AA(\%) = \frac{[(mg\ \ AA/g\ \ diet - (mg\ \ AA/g\ \ E1\ \ \times FI1) - (mg\ \ AA/g\ \ E2\ \ \times FI2))]}{mg\ \ AA\ \ in\ \ diet} \times 100$$

For the determination of the basal ileal endogenous losses of amino acid, the following formula was used (Adeola et al., 2016):

Basal ileal endogenous losses of amino acid.

$$Basal\ \ Ileal\ \ AAend = mg\ \ AA/g\ \ diet\ \ x\ \ (\%\ \ TiO2\ \ NDF\ \ diet/\ \ \%\ \ TiO2\ \ digesta)$$

The apparent ileal digestible and standardized ileal digestible crude protein and amino acids in corn HP-DDG were calculated by multiplying each AID and SID coefficient by the CP and AA content in the test ingredient.

2.5 Data analysis

Digestibility coefficients were established from the mean values obtained from the repetitions and the standard deviation of the means was subsequently calculated. Means that deviated from the treatment mean by more than 1.5 SDs were considered outliers.

Means obtained for AID and SID coefficients for lysine, methionine, tryptophan, arginine, glycine, phenylalanine plus tyrosine, and proline, respectively, from the same replicate in the treatment with corn HP-DDG were identified as outliers and removed.

3 Results and discussion

Co-products manufactured by the ethanol industry have been used extensively in animal production. Despite their advantages, the published literature regarding the nutritional value of such ingredients is not consistent, which restricts their utilization in pig feed. Such a gap in knowledge, for example, reflects the absence of information regarding the nutritional value of ethanol co-products and the limits of their utilization in pig feeds in the "Brazilian Tables for Poultry and Swine" (Rostagno et al., 2017), which has been the main reference for poultry and swine nutrition in Brazil. Consequently, researchers frequently use alternative references, such as the National Research Council (2012), which might not precisely reflect Brazilian conditions. The last revised edition of Nutrient Requirements of Swine (National Research Council, 2012) describes the crude protein (CP) content of corn HP-DDG manufactured using a processing method with FST technology as 49.7%. In the current study, the CP content in the ethanol industry co-product under study was equivalent to 44.4% and 40.4% on a dry matter and as-fed basis, respectively (Table 2). Other studies involving corn HP-DDG manufactured in Brazil reported similar protein values on a dry matter basis ranging from 46.5% to 45.1% CP (Palowski et al., 2021; Paula et al., 2021; Dias et al., 2023). Overall, our results suggest lower values for certain amino acids in corn HP-DDG compared to National Research Council (2012) on an as-fed basis, specifically, methionine (0.74% vs. 0.80%), threonine (1.61% vs. 1.90%), tryptophan (0.23% vs. 0.38%), and valine (2.15% vs. 2.19%). The only exception was lysine, which was slightly higher than NRC values (1.39% vs. 1.34%). The underlying reasons for the referred variations in protein and amino acid content might be the different processing methods utilized during the manufacturing of the ethanol co-products (temperature, cooking time, stem, etc.). Such variations reinforce the need to characterize the nutritional value of ethanol co-products manufactured according to the FST technique implemented by the Brazilian ethanol industry.

Basal endogenous losses, expressed in grams per kilogram of Dry Matter Intake (DMI), were determined in pigs fed a nitrogen-free diet (NDF). The essential amino acids lost were lysine (0.212 g/kg DMI), methionine (0.094 g/kg DMI), threonine (0.538 g/kg DMI), tryptophan (0.335 g/kg DMI), valine (0.418 g/kg DMI), isoleucine (0.286 g/kg DMI), leucine (0.509 g/kg DMI), histidine (0.175 g/kg DMI), and phenylalanine (0.280 g/kg DMI). For non-essential amino acids, arginine (0.409 g/kg DMI), alanine (0.569 g/kg DMI), cysteine (0.049 g/kg DMI), tyrosine (0.212 g/kg DMI),

TABLE 2 Analyzed nutrient composition of ingredients (as-fed basis).

Item	Corn HP-DDG[1]
Dry Matter, %	90.84
Crude Protein, %	40.41
Indispensable AA, %	
Lysine	1.39
Methionine	0.74
Threonine	1.61
Tryptophan	0.23
Arginine	1.78
Valine	2.10
Isoleucine	1.55
Leucine	4.94
Histidine	1.20
Phenylalanine	2.16
Dispensable AA, %	
Alanine	3.07
Cysteine	0.83
Tyrosine	1.73
Glycine	1.59
Serine	1.90
Proline	3.63
Hydroxyproline	0.02
Glutamic Acid	7.42
Aspartic Acid	2.77
Sum of Amino Acids %	40.65

[1]Corn HP-DDG (corn distillers dried grains with high protein, F S Bioenergia, Lucas do Rio Verde—MT, Brazil).

TABLE 3 Composition of diets used in the experiment (as-fed basis).

Ingredients, %	Nitrogen Free Diet	Corn HP-DDG
Corn HP-DDG	–	40.00
Soybean oil	4.00	–
Sugar	20.00	20.00
Corn starch	67.33	31.33
Dicalcium phosphate	1.96	1.96
Limestone	0.76	0.76
Vitamin Supplement	0.30	0.30
Mineral Supplement	0.25	0.25
Salt	0.40	0.40
Potassium carbonate	0.40	0.40
Magnesium Oxide	0.10	0.10
Cellulose	4.00	4.00
Titanium Dioxide	0.50	0.50
Total	100	100

[1]Provided the following quantities per kilogram of complete diet: Se as sodium selenite and selenium yeast, 75.0 mg/kg; vitamin A as retinyl acetate, 2,000 IU/kg; vitamin D3 as cholecalciferol, 375,000 IU/kg; vitamin E as DL-alpha tocopheryl, 6,250 UI/kg; vitamin K3 as menadione nicotinamide bisulfate 750.0 mg/kg; thiamin as thiamine mononitrate, 500.0 mg/kg; riboflavin, 1,500 mg/kg; pyridoxine as pyridoxine hydrochloride, 500.0 mg/kg; vitamin B12, 7500.00 mcg/kg; folic acid, 250.0 mg/kg; pantothenic acid as D-calcium pantothenate, 5,000.00 mg/kg; niacin, 8,750.00 mg/kg; biotin, 37.50 mg/kg.

[2]Provided the following quantities per kilogram of complete diet: Fe, 15.00 g/kg as iron sulfate, Cu, 40 g/kg as copper sulfate, Mn, 13 g/kg as manganese monoxide; Zn, 25 g/kg as zinc sulfate; I, 350.00 mg/kg as calcium iodate.

glycine (1.273 g/kg DMI), serine (0.555 g/kg DMI), proline (3.187 g/kg DMI), glutamic acid (0.695 g/kg DMI), and aspartic acid (0.366 g/kg DMI) were used. Using NFD, we noticed that the endogenous losses of proline and glycine were considerably high. Such outcomes are supported by previous research findings where NFD was used to estimate the loss of proteinaceous compounds in pigs (Kim et al., 2009; Urriola et al., 2009; Zhai and Adeola, 2011). The basal losses of essential amino acids observed herein were also similar to the mean values described by Adeola et al. (2016) in the literature review.

We also determined the apparent ileal digestibility (AID) and standardized ileal digestibility (SID) coefficients of CP and amino acids in corn high-protein dried distillers' grains (HP-DDG) in pigs. Our findings revealed AID and SID values of 74% and 80%, respectively (Table 5). These values are superior to the previously reported AID and SID values. Paula et al. (2021); Yang et al. (2021), and National Research Council (2012) described the AID and SID CP coefficients in HP-DDG in pigs as 63% and 67%, 64% and 77%, and 70% and 76%, respectively. Our coefficients are similar to those determined by Widmer et al. (2007). The authors reported AID and SID CP coefficients of HP-DDG in pigs of 72% and 80%, respectively. The wide variation in digestibility values (Table 5) has been previously highlighted by Stein (2008) who emphasized the influence of different manufacturing methods utilized by the ethanol industry.

The AID and SID amino acids (AAs) observed in this study were higher than those reported previously. The AID and SID values for the essential AAs were higher than those recently determined by Yang et al. (2021) and Paula et al. (2021). Our results are similar to those described by National Research Council (2012), except for lysine and tryptophan, whose AID values were equivalent to 65% and 69%, respectively, and the SID values were 82% and 69%, respectively. Comparing our findings with those of Widmer et al. (2007), we observed similar coefficients, except for lysine, tryptophan, and arginine, whose AID coefficients were 57%, 71%, and 75%, and SID coefficients were 64%, 81%, and 83%, respectively. The lower digestibility of such AAs may be associated with heat damage during the distillation process in DDG production. Lysine is particularly sensitive to temperature due to the Maillard reaction, in which

TABLE 4 Chemical and analysis of the composition of experimental diets (as-fed).

Ingredients	Nitrogen Free Diet	Corn HP-DDG
Dry Matter, %	91.54	91.89
Crude Protein, %	ND[1]	19.62
Indispensable AA, %		
Lysine	ND[1]	0.69
Methionine	ND[1]	0.37
Threonine	ND[1]	0.78
Tryptophan	0.04	0.36
Arginine	ND[1]	0.86
Valine	0.01	1.00
Isoleucine	ND[1]	0.74
Leucine	0.01	2.39
Histidine	ND[1]	0.57
Phenylalanine	ND[1]	1.04
Dispensable AA, %		
Alanine	0.01	1.48
Cystine	ND[1]	0.38
Tyrosine	ND[1]	0.77
Glycine	ND[1]	0.77
Serine	ND[1]	0.94
Proline	0.01	1.71
Hydroxyproline	ND[1]	0.01
Glutamic Acid	0.03	3.58
Aspartic Acid	0.04	1.35
Sum of Amino Acids	0.22	19.79

[1]ND, not detect.

its amino group reacts with reducing sugars in the presence of heat (Erbersdobler and Hupe, 1991; Paula et al., 2021). Our estimates for nonessential AA digestibility coefficients showed the same pattern as those found for essential AAs, which were higher than those reported in the literature. Notably, the physicochemical properties of ingredients are also determinants of AA digestibility, as highlighted by Paula et al. (2021), who found high SID AA values in corn DDG with high protein content and lower neutral detergent fiber.

The apparent and standardized ileal digestibility coefficients of crude protein (CP) and amino acids (AA) in corn high-protein dried distillers' grains (HP-DDG) are presented in Table 6. Except for lysine, whose AID and SID coefficients were greater, and histidine and phenylalanine, whose digestibility was similar, the SID values found herein for all other AAs were lower than those reported by Paula et al. (2021), who investigated corn HP-DDG produced using FST technology. Glycine, another exception, had a similar AID but lower SID coefficient compared with the Paula et al. (2021) estimates. The differences between our findings and those in the referred literature might be explained by the lower basal endogenous loss of glycine observed in our study.

The average AID and SID coefficients for essential AAs were 80.6% and 84.3%, respectively, whereas those for non-essential AAs were 76.1% and 82.3%, respectively. Our findings regarding the chemical composition and digestibility of AAs in Brazilian corn high-protein dried distillers' grains (HP-DDG) in pigs contribute to increasing the accuracy with which this ingredient is manipulated in feeds by the swine production industry. Pig nutritionists can design feeding programs with higher economic and environmental efficiency. The chemical composition and ileal digestibility coefficients of Brazilian corn high-protein dried distillers' grains (HP-DDG) presented herein whether compiled with published literature can be used for new revised editions of the Brazilian Tables for Poultry and Swine. Even though our outcomes are relevant and meaningful for swine nutrition, much

TABLE 5 Apparent ileal digestibility and standardized ileal digestibility coefficients of crude protein and amino acids in Corn HP-DDG.

	AID, %	SID[1]%	SD[2]	Review[3]
Crude Protein	74.04	80.87	6.31	70–84
Indispensable AA				
Lysine %	76.32	79.15	3.90	61–85
Methionine %	87.21	89.57	3.58	81–89
Met + Cys %	84.75	86.52	5.14	70–84
Threonine %	71.97	78.30	8.43	67–83
Tryptophan %	83.86	92.44	2.44	75–90
Arginine %	82.05	86.40	4.09	81–92
Valine %	76.64	80.47	6.58	74–85
Isoleucine %	77.08	80.61	6.56	74–87
Leucine %	83.91	85.87	5.18	84–90

(Continued)

TABLE 5 Continued

	AID, %	SID[1%]	SD[2]	Review[3]
Indispensable AA				
Histidine %	80.29	83.10	5.37	74–87
Phenylalanine %	82.34	84.82	4.82	81–89
Dispensable AA				
Alanine %	80.29	83.83	5.67	78–86
Cysteine %	83.69	84.88	5.63	70–84
Tyrosine %	81.93	84.45	5.19	67–83
Phe + Tyr %	83.66	86.16	3.77	
Glycine %	60.09	75.25	8.57	56–81
Serine %	77.68	83.12	5.97	77–86
Gly + Ser %	68.00	77.83	8.64	
Proline %	63.88	81.02	7.45	73–100
Glutamic Acid %	83.17	84.96	5.38	82–89
Aspartic Acid %	78.73	81.22	6.32	67–82

[1]Values for SID were calculated by correcting the AID value for basal endogenous losses. Basal endogenous losses were determined from pigs fed the Nitrogen Free Diet (g/kg of DMI): Lysine, 0.212; Methionine, 0.094; Threonine, 0.538; Tryptophan, 0.335; Arginine, 0.409; Valine, 0.418; Isoleucine, 0.286; Leucine, 0.509; Histidine, 0.175; Phenylalanine, 0.280; Alanine, 0.569; Cysteine, 0.049; Tyrosine, 0.212; Glycine, 1.273; Serine, 0.555; Proline, 3.187; Glutamic Acid, 0.695; Aspartic Acid, 0.366.
[2]SD, Mean standard deviation.
[3]Lower and higher values are cited in Section 3. Feeding applications of corn fermented protein coproducts in swine diets by Stein (2008).

TABLE 6 Apparent ileal digestible and standardized ileal digestible crude protein and amino acids in corn HP-DDG (as-fed basis).

	Corn HP-DDG	
	AID[1]	SID[2]
Crude Protein %	29.92	32.68
Indispensable AA		
Lysine %	1.06	1.10
Methionine %	0.64	0.66
Met + Cys %	1.33	1.35
Threonine %	1.15	1.26
Tryptophan %	0.19	0.21
Arginine %	1.46	1.53
Valine %	1.60	1.69
Isoleucine %	1.19	1.24
Leucine %	4.14	4.24
Histidine %	0.96	0.99
Phenylalanine %	1.77	1.83
Dispensable AA		
Alanine %	2.46	2.57
Cysteine %	0.69	0.70
Tyrosine %	1.41	1.46
Phe + Tyr %	3.25	3.35
Glycine %	0.95	1.19
Serine %	1.47	1.57
Gly + Ser %	2.37	2.71
Proline %	2.31	2.94
Glutamic Acid %	6.17	6.30
Aspartic Acid %	2.18	2.25

[1]AID, Apparent ileal digestible amino acids, as-fed.
[2]SID, Standardized ileal digestible amino acid, as-fed.

work must still be done towards characterizing ethanol industry co-products and clarifying the extent to which new processing techniques employed by the ethanol industry can affect the availability of nutrients in co-products.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The animal study was approved by the Ethics Committee for the Use of Production Animals at Universidade Federal de Viçosa under protocol number 59/2023. The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

SM: Writing – review & editing, Formal Analysis, Investigation, Writing – original draft. JB: Conceptualization, Data curation, Investigation, Supervision, Writing – original draft. AL: Formal Analysis, Investigation, Writing – original draft. BR: Investigation, Writing – original draft. IL: Conceptualization, Methodology, Resources, Visualization, Writing – review & editing. BM: Conceptualization, Resources, Visualization, Writing – review & editing. LR: Conceptualization, Methodology, Writing – review & editing. MH: Conceptualization, Data curation, Funding acquisition, Methodology, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

IL is a consultant for FS Bioenergia. BM is a manager at FS Bionergia.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be constructed as a potential conflict of interest.

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