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Apparent or Standardized Ileal Digestibility of Amino Acids of Diets Containing Different Protein Feedstuffs Fed at Two Crude Protein Levels for Growing Pigs

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ABSTRACT: The current study determined the apparent or standardized ileal digestibility of amino acids (**AID or SID of AA**) in growing pigs fed diets containing three protein feedstuffs with different fiber characteristics at two dietary crude protein (**CP**) levels. Twenty boars (Yorkshire × Landrace) with average initial bodyweight of 35 (± 2.6) kg were fitted with a simple T-cannula at the distal ileum. These pigs were offered six diets containing soybean meal (**SBM**), canola meal (**CM**) or corn distillers dried grains with solubles (**corn-DDGS**) that were either adequate (19%) or marginal (15%) in CP using a triplicated 6 × 2 Youden Square Design. Except for Met, Trp, Cys and Pro, AID of AA were greater ($p<0.05$) in the SBM diet compared with the CM diet. Apparent ileal digestibility for Gly and Asp were greater ($p<0.05$) in the SBM diet compared with the corn-DDGS diet. The AID of AA for Ile, Leu, Phe, Val, Ala, Tyr and Asp were greater ($p<0.05$) in the corn-DDGS diet compared with the CM diet. Standardized ileal digestibility of AA was greater ($p<0.05$) in the SBM diet compared with the CM diet for all AA except Trp and Pro. The SID of AA for Ile, Leu, Val, Ala, Tyr and Asp were greater ($p<0.05$) in the corn-DDGS diet compared with the CM diet. It was concluded that protein feedstuff affects ileal AA digestibility and is closely related to dietary fiber characteristics, and a 4 percentage units reduction in dietary CP had no effect on ileal AA digestibility in growing pigs.

Key words: Amino acids digestibility, Crude protein level, Growing pigs, Protein feedstuff.

INTRODUCTION

Fiber is a usual component in the pig diet and when included within reasonable levels, it promotes normal gastrointestinal tract function (Wenk, 2001). On the other hand, the negative effect of dietary fiber on energy and nutrient utilization is dependent on its physical and chemical

properties which differ among feedstuffs (Lenis et al., 1996). Cereal grains usually contribute the majority of fiber to the diet; but the contributions to dietary fiber from protein feedstuffs may also be substantial. The detergent fiber procedure categorizes fiber into neutral detergent fiber (**NDF**) that consists of hemicellulose, cellulose and lignin, acid detergent fiber (**ADF**) that consists of cellulose and lignin and acid detergent lignin (**ADL**) that consist mainly of lignin (NRC, 2012). The NDF, ADF and ADL contents in soybean meal (**SBM**) are 8.2, 5.3, and 1.1%, respectively (NRC, 2012). Canola meal (**CM**) may contain up to 35% crude protein (**CP**), but the NDF (23.8%), ADF (17.6%) and ADL (7.3%) contents are greater than are found in SBM (NRC, 2012). Corn-DDGS is the co-product of bioethanol produced from corn grain and may contain up to 27% CP (Olukosi and Adebiyi, 2013). The total fiber, NDF, and ADF contents in corn-DDGS are 31, 33 and 12%, respectively (NRC, 2012).

Excessive nitrogen (**N**) excretion by pigs may be mitigated by reducing the protein content of the diet (Lee et al., 2001). Lee et al. (2001) noted that reducing dietary CP content by up to 4 percentage units reduced N excretion by 20% in finishing pigs. Changes to dietary CP levels are often achieved by wholly replacing or partially substituting SBM with feedstuffs that contain lower CP content. Soybean meal, CM and corn-DDGS were used to determine the effect of differences in diet fiber composition on ileal amino acid (**AA**) digestibility in the current study because the fiber characteristics of these feedstuffs are different (NRC, 2012). The objective in the current study was to determine the effect of feeding, at two dietary protein levels, three protein feedstuffs that are different in their fiber composition and type on apparent or standardized ileal digestibility of amino acids (**AID or SID of AA**) for growing pigs. It was

hypothesized that feeding a protein feedstuff with greater fiber content at adequate or low dietary CP level will negatively affect ileal AA digestibility in pigs.

MATERIALS AND METHODS

Animals, management, diets and sample collection

All animal handling procedures were approved by the Purdue University Animal Care and Use Committee (USA) and the Animal Experiment Committee of the Scotland's Rural College (UK). Twenty male pigs (Yorkshire × Landrace) were obtained from the Animal Sciences Research and Education Centre of Purdue University for surgery. The pigs were fasted for 12 hours prior to the surgical procedure of fitting a T-cannula to the distal end of the ileum. The internal diameter, wings and length of the T-cannulas were 1.3, 2.5 and 5 centimeters, respectively. Comprehensive description of the surgical procedure and post-operative care was as described by Dilger et al. (2004). All the pigs were conscious within a short time after the surgery and were allowed a 14 d recovery period.

The average initial bodyweight (**BW**) of the pigs was 35 kg at the start of the current study. The dietary treatments were three protein feedstuffs (SBM, CM or corn-DDGS) and two protein levels (19 or 15%). In each period, two pigs with BW closest to the mean of the twenty pigs were offered a N-free diet to determine basal endogenous ileal AA flow. The remaining eighteen pigs were allocated to the experimental diets using a triplicated 6 × 2 Youden square design. Daily feed allowance was divided into two equal portions and offered in the morning and evening (0800 and 2000, respectively). Pigs were given *ad libitum* access to water throughout the study. Each experimental period lasted for seven days consisting of five days of adaptation to the diets

and two days of ileal digesta collection. Ileal digesta was collected for 12 hours on both days (d 6 and 7). Ileal digesta were collected in Whirlpak® bags containing 10 ml of 10% formic acid and stored frozen (-20^{o}C) prior to further analyses. Chromic oxide was added to the diets (5 g/kg of diet) as an indigestible index to enable determination of AID of AA and SID of AA by the index method (Kong and Adeola, 2014). The pigs were housed individually in smooth-walled pens within a facility equipped with temperature, light, and humidity control during the study.

Chemical analysis

Samples of the diets and ileal digesta were analyzed for dry matter (**DM**), N, AA, crude fiber (**CF**), NDF, ADF and chromium where necessary. Ileal digesta samples were freeze dried before AA analysis. Diet and ileal digesta samples were ground to pass through a 0.5 mm screen using a mill grinder (Retsch ZM 100, F. Kurt Retsch GmbH & Co.KG, Haan, Germany) before chemical analysis. Dry matter contents in the diets and ileal digesta were determined by drying samples at 100^{o}C for 24 hours. Nitrogen was determined by the combustion method (AOAC International 2006, method 968.06). For AA analyses, samples were hydrolyzed for 24 hours in 6 N hydrochloric acid at 110^{o}C under an atmosphere of N. For Met and Cys, performic acid oxidation was carried out before acid hydrolysis. The AA in the hydrolysate were determined by High Performance Liquid Chromatography after post-column derivatization [(AOAC International 2000, method 982.30E (a, b, c)]. Chromium was determined using the Inductively Coupled Plasma Atomic Emission Spectroscopy method following nitric/perchloric acid wet ash digestion (AOAC International, 2000, method 990.08). Crude fiber, NDF and ADF in the diets were determined using the ANKOM's proprietary 200 Filter Bag Technique in Ankom 200 Fiber Analyzer (Ankom Technology, Macedon, NY, USA).

104 **Calculations and statistical analyses**

105 Apparent ileal digestibility of AA was calculated using the index method. Basal endogenous
106 ileal flow of AA was calculated from a N-free diet using the index method. Standardized ileal
107 digestibility of AA was determined from the correction of AID of AA values for basal
108 endogenous ileal AA losses.

109 1. Basal ileal AA flow was calculated using the following equation:

$$\text{EAAF} = \text{AAo} \times \left(\frac{\text{Cri}}{\text{Cro}}\right)$$

110 where EAAF is endogenous ileal AA flow (mg/kg of DM intake); AAo is the AA content in
111 ileal digesta (mg/kg); Cr_i and Cr_o are the concentrations of chromium (mg/kg) in diet and ileal
112 digesta, respectively.

113 2. AID of AA was calculated using the following equation:

$$\text{AID of AA} = \left[1 - \left(\frac{\text{Cri}}{\text{Cro}}\right) \times \left(\frac{\text{AAo}}{\text{AAi}}\right)\right] \times 100$$

114 where AID of AA is apparent ileal digestibility of amino acid (%); Cr_i and Cr_o are the
115 concentrations of chromium in diet and ileal digesta, respectively; AA_o is the amino acid content
116 in the digesta and AA_i is the amino acid content in the diet.

117 3. SID of AA was calculated using the following equation:

$$\text{SID of AA} = \text{AID} + \left[\left(\frac{\text{EAAF}}{\text{AAi}}\right) \times 100\right]$$

118 where SID of AA is standardized ileal digestibility of AA (%); AID of AA is apparent ileal
119 digestibility of AA (%); EAAF is the endogenous basal ileal AA flow (g/kg of DM intake)
120 and AA_i is the amino acid content in the diet (g/kg of DM).

Data were analyzed using the Generalized Linear Models of Genstat Statistical Package (11th edition, VSN International) as a triplicated 6 × 2 Youden square design. The statistical model for this design was $y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + \varepsilon_{ijk}$ where μ is the overall mean, α_i is the protein feedstuff effect, β_j is the protein level effect, γ_k is the block effect, $(\alpha\beta)_{ij}$ is the interaction effect, and ε_{ijk} is the error term. The statistical model for this analysis included replicates with 5 degrees of freedom (**df**), experimental period with 1 df and dietary treatments with 5 df. Individual pig was the experimental unit. Least squares means were separated using the Tukey test with $P<0.05$ indicating statistical significance.

RESULTS

The ingredient and chemical composition of the diets used in the current study are presented in Table 1. The digestible energy contents were similar in the diets that contained adequate or reduced CP levels. Regardless of CP level, analyzed CF, NDF and ADF were lowest in the SBM diet. On the other hand, the CM diet contained the greatest levels of ADF and ADL whereas NDF was greatest in the corn-DDGS diet. The analyzed AA content of the diets used in the current study are presented in Table 2. The analyzed AA contents in the diets were similar to calculated values and mirrored the difference in the CP contents between the adequate- and reduced CP diets. The ingredient and chemical composition of the N-free diet used to determine basal endogenous ileal AA flow is presented in Table 3. As was expected, the CP and AA content in the N-free diet were either nil or very low.

Dry matter digestibility and AID of N and indispensable AA in growing pigs receiving diets with different protein feedstuffs and CP levels are presented in Table 4. Reducing dietary CP

level from 19 to 15% did not affect ileal DM digestibility or AID of AA in growing pigs. Ileal DM digestibility was greater ($p<0.05$) in the SBM diet compared with either the CM diet or corn-DDGS diet. With the exception of Met and Trp, AID of AA was greater ($p<0.05$) in the SBM diet compared with the CM diet. The AID of Ile, Leu, Phe and Val were greater ($p<0.05$) in the corn-DDGS diet compared with the CM diet. Apparent ileal digestibility of AA was similar in the SBM diet and the corn-DDGS diet. There was protein feedstuff × protein level interaction ($p<0.05$) for AID of Lys. The AID of Lys was greater ($p<0.05$) in the SBM and corn-DDGS diets compared with the CM diet in CP-adequate dietary treatments, whereas the AID of Lys did not differ among the reduced-CP dietary treatments.

Apparent ileal digestibility for dispensable AA and total amino acids (**TAA**) in growing pigs receiving diets containing the different protein feedstuffs and CP levels are presented in Table 5. Reducing dietary CP level from 19 to 15% did not affect AID of AA in growing pigs. Apparent ileal digestibility of Gly and Asp were greater ($p<0.05$) in the SBM diet compared with the corn-DDGS diet. With the exception of Cys and Pro, AID of AA was greater ($p<0.05$) in the SBM diet compared with the CM diet. The AID of Ala, Tyr and Asp were greater in the corn-DDGS diet compared with the CM diet. The AID of TAA was greater ($p<0.05$) in the SBM diet compared with the CM diet, but did not differ significantly from that of the corn-DDGS diet.

The standardized ileal digestibility of N and indispensable AA in growing pigs receiving diets containing different protein feedstuffs and CP levels are presented in Table 6. Reducing dietary CP level from 19 to 15% did not affect SID of AA in growing pigs. Except for Trp, SID of AA was greater ($p<0.05$) in the SBM diet compared with the CM diet. The SID of Ile, Leu and

Val were greater ($p<0.05$) in the corn-DDGS diet compared with the CM diet. Standardized ileal digestibility of AA was similar in the SBM diet and the corn-DDGS diet.

Standardized ileal digestibility of dispensable AA and TAA in growing pigs receiving diets containing different protein feedstuffs and CP level are presented in Table 7. Reducing dietary CP level from 19 to 15% did not affect SID of AA in growing pigs. The SID of Pro was not different among the dietary treatments. The SID of Gly and Asp was greater ($p<0.05$) in the SBM diet compared with the corn-DDGS diet. The SID of Tyr and Asp were greater in the corn-DDGS diet compared with the CM diet. Except for Pro, SID of AA was greater ($p<0.05$) in the SBM diet compared with the CM diet. The SID of TAA was greater ($p<0.05$) in the SBM diet compared with the CM diet. On the other hand, SID of TAA was not different between the SBM and corn-DDGS diet.

DISCUSSION

The objective of the current study was to determine the effect of protein feedstuff used, in relation to differences in dietary fiber characteristics and CP level on ileal AA digestibility in growing pigs.

Water-soluble dietary fiber may compromise protein and AA digestibility by increasing digesta viscosity, and as a consequence, reducing contact between digesta, digestive enzymes, and the absorptive surface (Choct et al., 2004). On the other hand, cellulose and lignin fractions in the diet may impair nutrient digestibility by increasing bulk and digesta transit (Wilfart et al., 2007). Calculated hemicellulose contents (NDF minus ADF) in the CP-adequate SBM, CM and corn-DDGS diets in the current study were 9.4%, 7.0% and 14.8%, respectively. Corresponding

values in the reduced-CP diets were 10.3%, 9.8% and 16.8%, respectively. These data show that the hemicellulose content in a diet formulated using corn-DDGS as protein feedstuff is approximately 50% greater compared with using SBM and there was a 100% increase in the level of ADF when CM or corn-DDGS were used as protein feedstuffs compared with using SBM.

Ileal DM digestibility was greater in the SBM diet compared with either the corn-DDGS or CM diet. The lower ileal DM digestibility observed in the diets containing greater levels of dietary fiber (CM and corn-DDGS) in the current study is consistent with reports that increased fiber levels reduces ileal DM digestibility in pigs (Lenis et al., 1996; Zhang et al., 2013). High levels of fiber in the pig diet have been reported to reduce palatability and voluntary feed intake (Zhang et al., 2013), increase endogenous N and AA flow (Lenis et al., 1996), decrease energy utilization (Sauer et al., 1991) and protein and AA digestibility (Dierick et al., 1983; Mosenthin et al., 1994; Zervas and Zijlstra, 2002). Because there were minimal differences (0.5 to 2.4%) in calculated hemicellulose levels in the SBM and CM diets in the current study, it appeared that the inferior AID of AA or SID of AA observed in the CM diet compared with the SBM diet was due to the anti-nutritive effects of the ADF fraction in the CM diet. On the other hand, there were minimal differences between the AID of AA or SID of AA of SBM and corn-DDGS diets considering that the latter contained greater levels of hemicellulose. It is possible however, that the differences in hemicellulose contents in the SBM and corn-DDGS diets was not large enough to negatively affect AID or SID of AA in the current study.

The nutritional gain from N degraded in the large intestine of growing pigs is limited (Sauer et al., 1991). Because excessive loss of N in pig manure is detrimental to the environment,

interventions that do not affect AA digestibility but reduces undigested protein flow to the large intestine are of particular interest. In the current study, reducing dietary CP level by 4 percentage units did not affect ileal AA digestibility. Otto et al. (2003) on the other hand, reported an increase in ileal AA digestibility in growing pigs receiving a corn-SBM diet containing 6% CP. The difference in ileal AA digestibility response to reduction in dietary CP in the current study and Otto et al. (2003) study may be because there was a much greater reduction in dietary CP level in the latter which may have triggered a greater response from pigs in order to meet nutrient requirement.

Except for the AID of Lys, there was no interaction between protein feedstuff and CP level on ileal AA digestibility in the current study. The interaction observed for the AID of Lys was due to a reduction in the AID of Lys from 85% in the CP-adequate SBM diet to 79% in the reduced-CP SBM diet. Notably, reducing the CP level in the SBM diet by 4 percentage units reduced the Lys content from 1.08 to 0.90% but caused minimal changes to dietary fiber levels. It is possible that the increase in dietary fiber content relative to Lys composition in the reduced-CP SBM diet was responsible for the reduction in the AID of Lys. Htoo et al. (2007) on the other hand, reported a decrease in AID of AA (except Lys, Met, Thr, Val and Pro) with a reduction in dietary CP from 24 to 20%. Differences in feedstuff and dietary protein levels used in the current study and that of Htoo et al. (2007) are factors that may affect ileal AA digestibility response to changes in CP level.

It was concluded that the type and level of dietary fiber affects ileal AA digestibility in growing pigs, and the choice of protein feedstuff explains some of the differences in dietary fiber type and level. The use of either SBM or corn-DDGS as protein feedstuff in the growing pig diet

produced similar ileal AA digestibility but CM was inferior to both SBM and corn-DDGS. In addition, reducing dietary protein level from 19 to 15% does not affect ileal AA digestibility in growing pigs.

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283

Table 1. Ingredient and chemical composition of diets to determine the effect of protein feedstuff and protein level on apparent or standardized ileal digestibility of amino acids in growing pigs.

	Adequate CP			Reduced CP		
Ingredients, %	Soybean meal	Canola meal	Corn-DDGS	Soybean meal	Canola meal	Corn-DDGS
Corn	67.0	58.4	42.9	77.1	72.8	63.2
Soybean meal	26.5	-	-	16.0	-	-
Canola meal	-	37.0	-	-	22.0	-
Corn-DDGS	-	-	51.0	-	-	30.0
Soybean oil	1.20	-	0.40	1.40	-	0.80
Limestone (38% Ca)	1.10	1.10	1.40	1.00	1.10	1.20
Monocalcium phosphate[1]	1.00	-	0.50	1.30	0.60	1.00
Common salt	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin premix[2]	0.15	0.15	0.15	0.15	0.15	0.15
Mineral premix[3]	0.10	0.10	0.10	0.10	0.10	0.10
Selenium premix[4]	0.05	0.05	0.05	0.05	0.05	0.05
L-Lysine HCl	0.10	0.40	0.70	0.10	0.40	0.70
Chromic oxide premix[5]	2.50	2.50	2.50	2.50	2.50	2.50
Energy and nutrients						
Digestible energy, kcal/kg	3,442	3,489	3,442	3,442	3,412	3,412
Crude protein, % (Analyzed)	19.5	19.9	19.8	15.5	15.8	15.1
Crude fiber, % (Analyzed)	3.50	6.90	5.80	3.23	4.65	3.79
NDF, % (Analyzed)	13.5	17.2	21.6	14.2	16.7	22.6
ADF, % (Analyzed)	4.08	10.2	6.88	3.91	6.93	5.83
ADL, % (Calculated)	0.51	2.90	1.47	0.43	1.85	0.99
Calcium, % (Calculated)	0.68	0.69	0.68	0.66	0.68	0.67
Phosphorus, % (Calculated)	0.58	0.58	0.59	0.59	0.57	0.60

[1]Contained 21% Ca and 18% P.
[2]Vitamin premix contained per kilogram of diet: vitamin A, 2,640 IU; vitamin D3, 264 IU; vitamin E, 17.6 IU; vitamin K activity, 2.4 mg; menadione, 880 µg; vitamin B12, 15.4 µg; riboflavin, 3.52 mg; D-pantothenic acid, 8.8 mg; niacin,13.2 mg
[3]Mineral premix contained per kilogram of premix: Cu (as copper chloride), 9 mg; I (as Ethylenediamine Dihydroiodide (EDDI)), 0.36 mg; Fe (as ferrous carbonate), 194 mg; Mn (as manganese oxide), 17 mg; and Zn (as zinc oxide), 149 mg
[4]Selenium premix (supplied 300 µg of Se per kilogram of diet)
[5]Chromic oxide premix contained 1 g chromic oxide added to 4 g of cornstarch).
Abbreviations are: Corn-distillers dried grains with solubles (corn-DDGS).

294 **Table 2.** Analyzed amino acids composition (dry matter basis) of diets to determine the effect of protein feedstuff and protein level on
295 apparent or standardized ileal digestibility of amino acids in growing pigs.

	Adequate CP			Reduced CP		
Analyzed AA Composition, %	Soybean meal	Canola meal	Corn-DDGS	Soybean meal	Canola meal	Corn-DDGS
Indispensable amino acids						
Arg	1.25	1.21	1.01	1.01	0.93	0.83
His	0.52	0.58	0.59	0.45	0.47	0.48
Ile	0.83	0.83	0.79	0.70	0.64	0.65
Leu	1.84	1.85	2.54	1.63	1.59	2.06
Lys	1.08	1.33	1.15	0.90	1.11	1.15
Met	0.30	0.44	0.42	0.29	0.32	0.33
Phe	0.99	0.93	1.02	0.83	0.75	0.85
Thr	0.73	0.83	0.75	0.59	0.65	0.60
Trp	0.25	0.25	0.18	0.19	0.18	0.15
Val	0.94	1.09	1.06	0.80	0.84	0.85
Dispensable amino acids						
Ala	1.06	1.13	1.54	0.95	0.97	1.26
Asp	1.87	1.47	1.37	1.47	1.14	1.15
Cys	0.30	0.46	0.40	0.29	0.35	0.32
Glu	3.64	3.81	3.48	3.07	3.10	3.04
Gly	0.82	1.01	0.88	0.67	0.77	0.70
Pro	1.26	1.48	1.70	1.11	1.25	1.42
Ser	0.83	0.79	0.81	0.69	0.67	0.66
Tyr	0.67	0.63	0.72	0.55	0.53	0.61
Total	19.2	20.3	20.6	16.3	16.4	17.2

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Table 3. Ingredient and chemical composition of nitrogen free diet to determine basal endogenous ileal amino acid loss in growing pigs

Ingredients,%	
Corn starch	76.9
Dextrose	10.0
Soy oil	3.00
Monocalcium phosphate[1]	2.00
Limestone (38% Ca)	0.50
Solka-floc	4.00
Salt	0.30
Vitamin premix[2]	0.15
Mineral premix[3]	0.10
Selenium premix[4]	0.05
Potassium carbonate	0.40
Magnesium oxide	0.10
Chromic oxide premix[5]	2.50
Energy and nutrients	
Crude protein (Analysed), %	0.16
Digestible energy, kcal/kg	3,749
Metabolizable energy, kcal/kg	3,722
Amino acids (Analysed), %	
Arg	0.01
His	0.00
Ile	0.04
Leu	0.05
Lys	0.00
Phe	0.02
Thr	0.01
Val	0.01
Met	0.01
Trp	0.00
Ala	0.02
Cys	0.01
Glu	0.06
Gly	0.01
Pro	0.03
Ser	0.01
Tyr	0.02
Asp	0.03
Total	0.38

[1]Contained 21% Ca and 18% P.
[2]Vitamin premix contained per kilogram of diet: vitamin A, 2,640 IU; vitamin D3, 264 IU; vitamin E, 17.6 IU; vitamin K activity, 2.4 mg; menadione, 880 µg; vitamin B12, 15.4 µg; riboflavin, 3.52 mg; D-pantothenic acid, 8.8 mg; niacin,13.2 mg).
[3]Mineral premix contained per kilogram of premix: Cu (as copper chloride), 9 mg; I (as Ethylenediamine Dihydroiodide (EDDI)), 0.36 mg; Fe (as ferrous carbonate), 194 mg; Mn (as manganese oxide), 17 mg; and Zn (as zinc oxide), 149 mg.
[4]Selenium premix (supplied 300 µg of Se per kilogram of diet).
[5]Chromic oxide premix contained 1 g chromic oxide added to 4 g of cornstarch).
Abbreviations are: Corn-distillers dried grains with solubles (corn-DDGS).

Table 4. Dry matter digestibility and apparent ileal digestibility (%) of nitrogen and indispensable amino acids in growing pigs in response to protein feedstuff used and crude protein level[1]

	DM	N	Arg	His	Ile	Leu	Lys	Phe	Thr	Met	Trp	Val
Effect of protein feedstuff[2]												
Soybean meal	67.9^{b}	74.2^{b}	86.3^{b}	83.3^{b}	79.7^{b}	82.3^{b}	82.2^{b}	81.6^{b}	69.7^{b}	83.4	79.4	74.1^{b}
Canola meal	56.5^{a}	62.0^{a}	79.4^{a}	75.0^{a}	66.8^{a}	73.1^{a}	72.0^{a}	71.3^{a}	56.4^{a}	77.4	74.6	62.6^{a}
Corn-DDGS	57.0^{a}	69.0^{ab}	81.4^{ab}	78.8^{ab}	74.6^{b}	82.3^{b}	77.4^{ab}	78.5^{b}	64.1^{ab}	81.5	72.4	71.4^{b}
SEM	2.98	2.04	1.48	1.61	1.93	1.82	1.51	1.96	2.45	1.71	1.79	2.08
Effect of crude protein level[3]												
Adequate (19% CP)	60.2	70.2	83.6	79.7	74.3	79.8	76.7	77.7	65.0	82.2	77.3	70.3
Reduced (15% CP)	61.0	66.8	81.3	78.5	73.4	78.9	78.0	76.8	62.1	79.4	73.5	68.8
SEM	2.44	1.70	1.21	1.32	1.58	1.48	1.23	1.61	2.00	1.40	1.46	1.71
P-values for main effects and interaction												
Protein feedstuff	0.030	0.009	0.017	0.013	<0.001	0.002	0.002	0.003	0.009	0.068	0.102	0.005
Protein level	0.823	0.261	0.227	0.578	0.699	0.678	0.532	0.697	0.389	0.190	0.170	0.573
Feedstuff × protein level	0.461	0.233	0.208	0.267	0.388	0.379	0.045	0.391	0.321	0.813	0.333	0.359

[1]Values are mean of 6 replicates.
[2]For the effect of protein feedstuff, within a column, means followed by same or no superscript do not differ ($p>0.05$).
[3]For the effect of crude protein level, within a column, means followed by same or no superscript do not differ ($p>0.05$).
Abbreviations are: dry matter (DM), corn distillers dried grains with solubles (corn-DDGS), standard error of the mean (SEM)

Table 5. Apparent ileal digestibility (%) of total- and dispensable amino acids in growing pigs in response to protein feedstuff used and crude protein level[1]

	Ala	Cys	Glu	Gly	Pro	Ser	Tyr	Asp	TAA
Effect of protein feedstuff[2]									
Soybean meal	75.9^{b}	73.2	84.8^{b}	69.1^{b}	67.1	76.9^{b}	79.9^{b}	77.4^{c}	77.9^{b}
Canola meal	67.4^{a}	64.0	78.3^{a}	58.1^{a}	64.6	63.8^{a}	69.3^{a}	60.4^{a}	68.2^{a}
Corn-DDGS	77.3^{b}	71.5	81.4^{ab}	59.1^{a}	74.1	71.3^{ab}	77.7^{b}	68.4^{b}	74.9^{ab}
SEM	1.87	2.05	1.59	2.55	3.23	2.04	1.87	2.08	1.80
Effect of crude protein level[3]									
Adequate (19% CP)	74.3	70.1	82.1	64.1	71.7	71.5	76.5	69.2	74.7
Reduced (15% CP)	73.0	69.4	81.1	60.2	65.5	70.2	75.1	68.8	73.0
SEM	1.53	1.68	1.30	2.09	2.65	1.67	1.53	1.69	1.47
P-values for main effects and interaction									
Protein feedstuff	0.007	0.057	0.041	0.006	0.111	0.002	0.002	<0.001	0.017
Protein level	0.582	0.838	0.644	0.182	0.106	0.625	0.548	0.911	0.529
Feedstuff × protein level	0.331	0.492	0.442	0.586	0.652	0.220	0.264	0.233	0.223

[1]Values are mean of 6 replicates.
[2]For the effect of protein feedstuff, within a column, means followed by same or no superscript do not differ ($p>0.05$).
[3]For the effect of crude protein level, within a column, means followed by same or no superscript do not differ ($p>0.05$).
Abbreviations are: corn distillers dried grains with solubles (corn-DDGS), total amino acids (TAA), standard error of the mean (SEM)

Table 6. Standardized ileal digestibility (%) of nitrogen and indispensable amino acids in growing pigs in response to protein feedstuff used and crude protein level[1]

	N	Arg	His	Ile	Leu	Lys	Phe	Thr	Met	Trp	Val
Effect of protein feedstuff[2]											
Soybean meal	81.2^{b}	90.4^{b}	86.3^{b}	83.2^{b}	84.9^{b}	86.3^{b}	84.7^{b}	76.4^{b}	87.8^{b}	83.9	79.5^{b}
Canola meal	68.8^{a}	83.7^{a}	77.8^{a}	70.5^{a}	75.8^{a}	75.4^{a}	74.6^{a}	62.4^{a}	79.5^{a}	79.3	67.5^{a}
Corn-DDGS	76.0^{ab}	86.4^{ab}	81.6^{ab}	78.3^{b}	84.3^{b}	80.9^{ab}	81.5^{ab}	70.6^{ab}	84.5^{ab}	78.4	76.3^{b}
SEM	2.02	1.51	1.61	1.98	1.81	1.53	1.92	2.46	1.68	1.82	2.07
Effect of crude protein level[3]											
Adequate (19% CP)	76.4	87.6	82.3	77.6	82.1	80.2	80.6	70.7	83.9	81.8	74.9
Reduced (15% CP)	74.6	86.2	81.7	77.4	81.6	81.9	80.3	69.3	81.6	79.3	74.4
SEM	1.65	1.24	1.32	1.62	1.49	1.25	1.58	2.01	1.39	1.48	1.70
P-values for main effects and interaction											
Protein feedstuff	0.008	0.026	0.010	<0.001	0.002	<0.001	0.004	0.006	0.047	0.205	0.004
Protein level	0.561	0.482	0.764	0.940	0.807	0.397	0.886	0.673	0.253	0.363	0.866
Feedstuff × protein level	0.225	0.191	0.258	0.359	0.371	0.055	0.375	0.314	0.760	0.315	0.333

[1]Values are mean of 6 replicates.
[2]For the effect of protein feedstuff, within a column, means followed by same or no superscript do not differ (p>0.05).
[3]For the effect of crude protein level, within a column, means followed by same or no superscript do not differ (p>0.05).
Abbreviations are: corn distillers dried grains with solubles (corn-DDGS), standard error of the mean (SEM)

Table 7. Standardized ileal digestibility (%) of total- and dispensable amino acids in growing pigs in response to protein feedstuff used and crude protein level[1]

	Ala	Cys	Glu	Gly	Pro	Ser	Tyr	Asp	TAA
Effect of protein feedstuff[2]									
Soybean meal	80.9^{b}	77.6^{b}	87.2^{b}	85.0^{b}	87.4	82.3^{b}	83.6^{b}	81.4^{c}	84.3^{b}
Canola meal	72.2^{a}	67.2^{a}	80.6^{a}	71.5^{a}	82.3	69.5^{a}	73.1^{a}	65.6^{a}	74.4^{a}
Corn-DDGS	80.9^{b}	75.1^{ab}	83.8^{ab}	74.1^{a}	89.6	77.0^{ab}	81.0^{b}	73.7^{b}	80.9^{ab}
SEM	1.90	2.01	1.59	2.60	3.18	2.02	1.86	2.09	1.75
Effect of crude protein level[3]									
Adequate (19% CP)	78.5	73.5	84.2	77.3	88.2	76.6	79.8	73.4	80.3
Reduced (15% CP)	77.8	73.5	83.7	76.8	84.8	76.3	79.0	74.2	79.8
SEM	1.56	1.65	1.30	2.13	2.61	1.65	1.52	1.71	1.43
P-values for main effects and interaction									
Protein feedstuff	0.011	0.031	0.039	0.001	0.274	0.002	0.003	<0.001	0.015
Protein level	0.772	0.993	0.793	0.869	0.370	0.923	0.738	0.807	0.845
Feedstuff × protein level	0.315	0.437	0.433	0.595	0.629	0.226	0.271	0.218	0.210

[1]Values are mean of 6 replicates.
[2]For the effect of protein feedstuff, within a column, means followed by same or no superscript do not differ (p>0.05).
[3]For the effect of crude protein level, within a column, means followed by same or no superscript do not differ (p>0.05).
Abbreviations are: corn distillers dried grains with solubles (corn-DDGS), total amino acids (TAA), standard error of the mean (SEM)