Kansas State University
College of Agriculture

SWINE DAY
2026

The Apparent Ileal Digestibility and Standardized Ileal Digestibility of Crude Protein and Amino Acids in Corn, White Sorghum, and Red Sorghum Fed to Growing Pigs

Walter G. Friesen[1], Diego A. Lopez[1], Jason C. Woodworth[2], Jordan T. Gebhardt[3], Matt D. Miesner [3], and Chad B. Paulk[1]

Summary

An experiment was conducted to determine the apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of crude protein (CP) and amino acids (AA) in corn, white sorghum, and red sorghum. Twelve barrows were surgically fitted with a T-cannula at the distal ileum and were randomly allotted to a replicated 3 × 3 Latin square design with three diets and three periods for the determination of AID and SID of CP and AA. Previously published values of basal endogenous losses were used to calculate the SID of CP and AA. Treatments consisted of diets containing corn, white sorghum, or red sorghum as the sole source of dietary protein. Data were analyzed using the GLIMMIX procedure of SAS (v. 9.4, SAS Institute, Inc., Cary, NC) as a replicated completely randomized Latin square design. There was an overall grain effect ($P < 0.030$) for SID of Arg, His, Leu, Lys, Met, Phe, Val, Asp, Glu, Tyr, and total indispensable AA. Corn had increased ($P < 0.05$) SID of His and Met compared with red or white sorghum. Red sorghum and corn were similar in SID of Leu, Lys, and Glu, however, both had increased ($P < 0.05$) SID of Leu, Lys, and Glu compared with white sorghum. Corn had increased ($P < 0.05$) SID of Arg, Phe, Val, Tyr, and total indispensable AA compared with white sorghum; however, red sorghum did not differ from corn or white sorghum. Red sorghum had increased ($P < 0.05$) SID of Asp compared with white sorghum; however, corn did not differ from red or white sorghum. There was a tendency ($P < 0.10$) for a treatment effect with red sorghum and corn having numerically greater SID of Ile and Ala compared with white sorghum. Red sorghum tended to have increased ($P = 0.077$) SID of Trp compared with white sorghum. No differences were observed in SID of CP or the remaining indispensable or dispensable AA. In conclusion, corn and red sorghum were similar in SID of most AA when fed to pigs and both had improved digestibility compared with that of white sorghum.

[1] Department of Grain Science and Industry, Kansas State University.
[2] Department of Animal Sciences and Industry, Kansas State University.
[3] Department of Diagnostic Medicine/Pathobiology, College of Veterinary Medicine, Kansas State University.

Keywords: amino acid digestibility, corn, white sorghum, red sorghum

Introduction

Corn is the most common cereal grain included in commercial swine diets. However, with increased feed ingredient prices and as sorghum becomes increasingly available, sorghum may be used to partially or completely replace corn in rations with adequate performance when properly balancing nutrient content and digestibility4. The United States, and specifically Kansas, is a major contributor to global sorghum production; however, the total production of sorghum in the U.S. comprises numerous varieties including red sorghum, tannin sorghum, white sorghum, and mixed sorghum grains.

Of these different varieties, red and white sorghum are most commonly produced in the U.S. Red or bronze sorghum is used across multiple sectors of production including ethanol fermentation, feed grain, and forage, whereas white sorghum is primarily used in human food production5. Regardless of the intended use of the differing grain varieties, varying lots and varieties may be used as feedstock for livestock production. Subsequently, nutrient content and digestibility may differ from what is used in diet formulation or expected upon delivery. Furthermore, common nutrient databases such as the NRC6 may not specifically define the nutrient content or digestibility values for the complete range of grain varieties available for swine feedstuffs. Therefore, the evaluation of specific sorghum varieties becomes essential for accurate diet formulation and further animal performance. Thus, the objective of this experiment was to determine the AID, SID, and SID concentration of CP and AA in corn, white sorghum, and red sorghum when fed to growing pigs.

Materials and Methods

The protocol used in this experiment was approved by the Institutional Animal Care and Use Committee of Kansas State University (Manhattan, KS), and conducted in a totally enclosed, environmentally regulated facility at the Kansas State University Swine Teaching and Research Center in Manhattan, KS.

Grain sourcing

Yellow corn and red sorghum were acquired locally from Mid Kansas Cooperative Association (Manhattan, KS), whereas white sorghum was obtained from NuLife Market (Scott City, KS). Nutrient content of grain sources used for this experiment was analyzed at a commercial laboratory and is shown in Table 1. Sorghum grain sources were considered equal, including nutrient coefficient values used for diet formulation[6].

Amino acid digestibility

Dietary treatments were formulated to contain each individual grain source as the sole source of dietary energy and protein provided to pigs (Table 2). All other nutrients were

[4] Goodband, B., R. Sulabo, and M. Tokach. 2019. Feed value benefits of sorghum for swine. Sorghum Checkoff. https://www.sorghumcheckoff.com/wp-content/uploads/2021/11/2019_10_01_SwineFeedingGuide_NewLogo.pdf

[5] USDA-AMS. 2026. Official United States Standards for Grain, 7 CFR Part 810. Subpart I: United States Standards for Sorghum. https://www.ecfr.gov/current/title-7/subtitle-B/chapter-VIII/subchapter-A/part-810. (Accessed 9 July 2026).

[6] Nutrient Requirements of Swine: Eleventh Revised Edition. 2012. National Academies Press, Washington, DC.

provided to meet or exceed requirements for pigs between 220 and 298 lb6. Titanium dioxide (0.5%) was included in all dietary treatments as an indigestible marker for the calculation of AID and SID of CP and AA.

All diets were fed in meal form and dietary treatments were manufactured at the O.H. Kruse Feed Technology and Innovation Center in Manhattan, KS, in accordance with current good manufacturing practices. Grain sources were individually ground using a three-high RMS roller mill (RMS Model 924) achieving a target particle size of 550 µm (±50 µm). Grain particle size analysis was conducted according to the ANSI/ASAE S319.2 standard particle size analysis method as described by Kalivoda et al.7. Each dietary treatment was mixed using a 2,000-lb twin-shaft counterpoise mixer (Hayes and Stolz, model TRDB63-0152, Fort Worth, TX) for 180 s. After mixing, the mash feed was discharged and packaged in 50-lb bags, where every second bag was sampled using a probe to provide a composite mash feed sample for each dietary treatment.

A total of 12 barrows (average initial BW: 236 ± 3.2 lb) were surgically equipped with a T-cannula in the distal ileum and were individually housed in pens (4.0 ft × 4.0 ft) equipped with a self-feeder, nipple waterer, and a slatted floor. The animals were allotted to a replicated 3 × 3 Latin square design with three periods of 7 d, and three dietary treatments. Therefore, each diet was fed to four pigs in each period for a total of 12 replicate pigs per dietary treatment. Pigs were fed 2.8 times the maintenance requirement for ME (i.e., 90 kcal/lb BW0.60; NRC, 2012)6 and had ad libitum access to water throughout the experiment. The daily feed allowance was divided and fed in two equal meals at 0800 and 1400 h.

The first 5 d of each period were considered the adaptation period to the diet.

Ileal sample collection took place on d 6 and 7. Ileal samples were collected for 8 h by removing the lid of the cannula, attaching a plastic bag to the barrel of the cannula, and securing it with a plastic cable tie. The digesta flowing into the bag were collected every 30 min or every time the bag was full. Digesta samples were immediately stored at -4°F to prevent bacterial degradation of AA. Digesta samples were thawed, subsampled, lyophilized, and ground in preparation for laboratory analysis.

Samples of individual ingredients, diets, and ileal digesta were shipped to the Experiment Station Chemical Laboratories (University of Missouri, Columbia, MO) and analyzed for DM (method 930.15; AOAC, 2019)8, nitrogen using the combustion method in a LECO analyzer (method 990.03; AOAC, 2019)8, and AA (method 982.30 E [a, b, c]; AOAC, 2019)8. Crude protein was calculated as nitrogen × 6.25. Diet and ileal digesta samples were also analyzed for titanium following the method described by Myers et al.9. Diet samples were also analyzed for ash (method 942.05; AOAC, 2019)8, crude fiber (method 978.10; AOAC, 2019)8, and crude fat (method 920.39; AOAC, 2019)8.

[7] Kalivoda, J. R., C. K. Jones, and C. R. Stark. 2017. Impact of varying analytical methodologies on grain particle size determination. J. Anim. Sci. 95:113–119. doi:10.2527/jas.2016.0966.

[8] AOAC. 2019. Official methods of analysis of AOAC int. 21st Ed. AOAC Int., Rockville, MD.

[9] Myers, W. D., P. A. Ludden, V. Nayigihugu, and B. W. Hess. 2004. Technical note: a procedure for the preparation and quantitative analysis of samples for titanium dioxide. J. Anim. Sci. 82:179–183. doi:10.2527/2004.821179x

The AID and SID of CP and AA were calculated as described by Stein et al.10. The values for the basal endogenous losses of CP and AA used to calculate SID were obtained from Adeola et al.11.

Statistical analyses

Data were analyzed using the GLIMMIX procedure of SAS (SAS Institute Inc., Cary, NC) with pig as the experimental unit. Diet was the fixed effect and pig and period were random effects. Least squares means were calculated for each independent variable, and means were separated using the PDIFF option. Studentized residuals were calculated for each observation. Observations with a studentized residual outside of ±3 were considered outliers and removed. Treatment differences were considered significant at $P \leq 0.05$ and marginally significant at $0.05 < P \leq 0.10$.

Results and Discussion

The chemical analysis of the grain sources was within expected ranges for DM, CP, ash, and most AA6. However, white sorghum was lower in ether extract (2.40%) and crude fiber (1.51%) content, whereas Lys (0.31%) was greater than published results.

There was no evidence of differences in AID of CP, Ile, Asp, Cys, Gly, total dispensable AA, or total AA digestibility between any of the grain sources (Table 3). There was an overall grain effect ($P \leq 0.044$) for the AID of DM, Arg, His, Leu, Lys, Met, Phe, Thr, Trp, Val, Glu, and Tyr. Corn had increased ($P < 0.05$) AID of Arg, His, Lys, and Met compared with either red or white sorghum grain. Corn and red sorghum were similar in AID of DM, Leu, and Glu, however, both were increased ($P < 0.05$) compared with white sorghum. Red sorghum had increased ($P < 0.05$) AID of Thr and Trp compared with corn, while white sorghum did not differ from red sorghum or corn. Red sorghum had increased ($P < 0.05$) AID of Val and Tyr compared with white sorghum, while corn did not differ from red or white sorghum. Although there was an overall treatment effect ($P = 0.044$) for AID of Phe, mean separation did not detect any differences among individual grain sources. However, there was a tendency for red sorghum and corn to be higher ($P < 0.10$) for AID of Phe than white sorghum. Red sorghum and corn tended to be higher ($P < 0.10$) for AID of total indispensable AA, while red sorghum tended to be increased ($P < 0.10$) for AID of Ala and Ser.

There was no evidence of difference in SID of CP, Thr, Cys, Gly, Ser, total dispensable AA, or total AA digestibility between the grain sources (Table 4). There was an overall grain effect ($P < 0.03$) for SID of Arg, His, Leu, Lys, Met, Phe, Val, Asp, Glu, Tyr, and total indispensable AA. Corn had increased ($P < 0.05$) SID of His and Met compared with red or white sorghum. Red sorghum and corn were similar in SID of Leu, Lys, and Glu, however both were increased ($P < 0.05$) compared with white sorghum. Corn had increased ($P < 0.05$) SID of Arg, Phe, Val, Tyr, and total indispensable AA compared with white sorghum; however, red sorghum did not differ from corn or white sorghum. Red sorghum had increased ($P < 0.05$) SID of Asp compared with white sorghum; however, corn did not differ from red or white sorghum. Red sorghum and corn

[10] Stein, H. H., M. F. Fuller, P. J. Moughan, B. Sève, R. Mosenthin, A. J. M. Jansman, J. A. Fernández, and C. F. M. De Lange. 2007. Definition of apparent, true, and standardized ileal digestibility of amino acids in pigs. Livest. Sci. 109:282–285. doi:10.1016/j.livsci.2007.01.019.

[11] Adeola, O., P. C. Xue, A. J. Cowieson, and K. M. Ajuwon. 2016. Basal endogenous losses of amino acids in protein nutrition research for swine and poultry. Anim. Feed Sci. Technol. 221:274–283. doi:10.1016/j.anifeedsci.2016.06.004.

tended to have increased (P < 0.10) SID of Ile and Ala compared with white sorghum. Red sorghum tended to have increased (P < 0.10) SID of Trp compared with white sorghum or corn.

There was no evidence of difference for the SID concentration of Arg or Gly between the grain sources, however there was an effect (P < 0.001) of grain source in the remaining concentrations of CP and AA (Table 5). Corn had a reduced (P < 0.05) SID concentration of CP, Thr, and Asp compared with red or white sorghum. Red sorghum had increased (P < 0.05) SID concentration of Ile, Leu, Phe, Val, Ala, Glu, Ser, Tyr, total indispensable AA, total dispensable AA, and total SID AA concentration compared with corn, while white sorghum was intermediate. Corn and red sorghum were similar in SID concentration of His and Met, however, both were increased (P < 0.05) compared with white sorghum. Corn and white sorghum were similar in SID concentration of Lys, however, both were increased (P < 0.05) compared with red sorghum. White sorghum was increased (P < 0.05) for SID concentration of Trp compared with corn, while red sorghum was intermediate. There was a tendency for red sorghum to have increased (P < 0.10) SID concentration of Cys compared with corn or white sorghum.

In conclusion, the analyzed CP and AA content of corn and red sorghum was within expected ranges6. White sorghum had similar analyzed content of CP and most AA; however, a greater Lys content than expected (NRC, 2012; Thomas et al., 2020)6,12. Corn and red sorghum were similar in SID of most AA when fed to pigs, however, the digestibility of both was greater compared with that of white sorghum. Red and white sorghum had greater SID concentrations of CP and most AA compared with corn. However, white sorghum was reduced in SID CP and AA concentration compared with red sorghum. White sorghum and corn had increased SID Lys compared with red sorghum.

Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned. Persons using such products assume responsibility for their use in accordance with current label directions of the manufacturer.

[12] Thomas, L. L., C. D. Espinosa, R. D. Goodband, H. H. Stein, M. D. Tokach, S. S. Dritz, J. C. Woodworth, and J. M. DeRouchey. 2020. Nutritional evaluation of different varieties of sorghum and the effects on nursery pig growth performance. J. Anim. Sci. 98:skaa120. doi:10.1093/jas/skaa120.

Table 1. Chemical composition of grain varieties (as-fed basis)[1, 2]

Item, %	Corn	White sorghum	Red sorghum
DM	87.89	88.71	87.37
CP	7.63	9.75	10.31
Ether extract	3.08	2.40	2.81
Crude fiber	1.75	1.51	1.80
Ash	1.27	1.44	1.30
Indispensable AA			
Arg	0.36	0.39	0.37
His	0.22	0.22	0.23
Ile	0.27	0.38	0.40
Leu	0.97	1.20	1.38
Lys	0.28	0.31	0.24
Met	0.16	0.16	0.17
Phe	0.39	0.50	0.54
Thr	0.29	0.34	0.34
Trp	0.05	0.09	0.08
Val	0.38	0.48	0.51
Dispensable AA			
Ala	0.61	0.82	0.96
Asp	0.55	0.68	0.69
Cys	0.17	0.17	0.18
Glu	1.54	2.00	2.24
Gly	0.30	0.32	0.33
Ser	0.36	0.41	0.45
Tyr	0.21	0.29	0.31

[1] Yellow Corn, MKC (Manhattan, KS); White Sorghum, NuLife Market (Scott City, KS); Red Sorghum, MKC (Manhattan, KS).

[2] Grain sources were analyzed in duplicate at Experiment Station Chemical Laboratories (University of Missouri, Columbia, MO)

Table 2. Composition of experimental diets (as-fed basis)[1,2]

Item, %	Corn	White sorghum	Red sorghum
Corn	96.49	---	---
Sorghum	---	96.54	96.54
Monocalcium phosphate, 21% P	1.35	1.25	1.25
Calcium carbonate	0.90	0.95	0.95
Sodium chloride	0.50	0.50	0.50
Trace mineral premix	0.13	0.13	0.13
Vitamin premix	0.13	0.13	0.13
Titanium dioxide	0.50	0.50	0.50
Total	100.00	100.00	100.00
Analyzed composition[3], %			
DM	88.01	88.59	87.78
CP	8.19	9.46	9.69
Ether extract	3.84	1.86	2.33
Crude fiber	2.60	1.33	1.74
Ash	3.89	3.22	3.41
Indispensable AA			
Arg	0.43	0.36	0.38
His	0.30	0.29	0.28
Ile	0.28	0.40	0.42
Leu	0.83	1.26	1.43
Lys	0.35	0.23	0.25
Met	0.18	0.18	0.18
Phe	0.37	0.51	0.55
Thr	0.30	0.32	0.34
Trp	0.06	0.08	0.08
Val	0.42	0.50	0.54
Dispensable AA			
Ala	0.56	0.89	0.98
Asp	0.60	0.65	0.72
Cys	0.17	0.18	0.18
Glu	1.39	2.08	2.30
Gly	0.34	0.30	0.32
Ser	0.35	0.40	0.43
Tyr	0.27	0.35	0.39

[1]Diets were formulated such that individual grain sources were the sole source of dietary protein. Sorghum sources were considered equal considering formulation coefficients derived from the NRC (2012). All other nutrients were provided to meet recommendations for growing pigs, 220 to 298 lb (NRC)6.

[2] Yellow Corn, MKC (Manhattan, KS); White Sorghum, NuLife Market (Scott City, KS); Red Sorghum, MKC (Manhattan, KS).

[3] Dietary treatments were analyzed in duplicate at Experiment Station ChemicalLaboratories (University of Missouri, Columbia, MO)

Table 3. The apparent ileal digestibility (AID) coefficient of DM, CP and AA in experimental diets[1,2]

Item, %	Corn	White sorghum	Red sorghum	SEM	*P* =
DM	76.3[a]	72.7[b]	76.1[a]	0.961	0.008
CP	56.1	55.7	57.3	3.233	0.828
Indispensable AA					
Arg	75.1[a]	65.6[b]	63.7[b]	3.183	0.001
His	78.5[a]	71.2[b]	72.3[b]	0.899	0.001
Ile	67.1	64.9	69.5	1.988	0.130
Leu	80.5[a]	73.5[b]	79.1[a]	1.426	0.002
Lys	60.9[a]	45.2[b]	50.3[b]	3.547	0.001
Met	83.4[a]	73.4[b]	76.1[b]	1.305	0.001
Phe	74.8[x]	70.2[y]	74.4[x]	1.613	0.044
Thr	49.0[b]	53.0[ab]	57.3[a]	2.964	0.039
Trp	69.9[b]	72.9[ab]	77.8[a]	1.649	0.006
Val	69.0[ab]	65.5[b]	70.8[a]	1.624	0.025
Total	71.8[x]	67.2[y]	71.0[xy]	1.821	0.061
Dispensable AA					
Ala	70.4[xy]	69.1[y]	73.9[x]	2.200	0.077
Asp	62.7	60.5	65.6	2.471	0.101
Cys	61.9	61.4	62.1	2.019	0.960
Glu	78.2[a]	72.9[b]	77.9[a]	1.527	0.010
Gly	26.6	26.2	26.0	8.700	0.994
Ser	64.9[y]	65.5[xy]	69.3[x]	2.088	0.067
Tyr	71.7[ab]	67.9[b]	73.0[a]	1.817	0.045
Total	58.4	61.4	64.6	4.097	0.126
Total AA	64.4	63.9	67.2	2.950	0.315

[a-b] Means within a row lacking a common superscript are different (P < 0.05).

[x-y] Means within a row lacking a common superscript tended to differ (P < 0.10).

[1] Effect of grain source on AID of DM, CP, and AA (n = 12).

[2] Yellow Corn, MKC (Manhattan, KS); White Sorghum, NuLife Market (Scott City, KS); Red Sorghum, MKC (Manhattan, KS).

Table 4. The standardized ileal digestibility (SID) of CP and AA in experimental diets[1,2]

Item, %	Corn	White sorghum	Red sorghum	SEM	*P* =
CP	74.8	71.8	72.9	3.233	0.235
Indispensable AA					
Arg	87.2[a]	80.3[b]	81.6[ab]	2.405	0.012
His	84.4[a]	77.3[b]	78.5[b]	0.899	0.001
Ile	76.6[x]	71.6[y]	75.7[xy]	1.988	0.069
Leu	85.9[a]	77.0[b]	82.1[a]	1.426	0.001
Lys	71.0[a]	60.5[b]	66.6[a]	2.885	0.001
Met	88.5[a]	78.5[b]	81.1[b]	1.306	0.001
Phe	82.0[a]	75.4[b]	79.2[ab]	1.613	0.008
Thr	63.7	67.0	70.3	2.964	0.119
Trp	84.6[xy]	83.9[y]	88.7[x]	1.649	0.077
Val	79.7[a]	74.4[b]	79.0[ab]	1.624	0.015
Total	80.7[a]	74.7[b]	77.9[ab]	1.822	0.021
Dispensable AA					
Ala	79.9[x]	75.1[y]	79.2[xy]	2.200	0.057
Asp	74.6[ab]	71.5[b]	77.1[a]	1.984	0.025
Cys	72.3	71.2	71.7	2.019	0.891
Glu	84.0[a]	76.7[b]	81.3[a]	1.526	0.002
Gly	65.6	70.2	66.9	8.700	0.696
Ser	82.9	81.1	83.5	2.088	0.439
Tyr	84.8[a]	78.0[b]	82.0[ab]	1.817	0.008
Total	78.4	76.7	78.4	4.097	0.779
Total AA	79.1	75.6	77.9	2.951	0.309

[a-b] Means within a row lacking a common superscript are different (P < 0.05).

[x-y] Means within a row lacking a common superscript tended to differ (P < 0.10).

[1] Effect of grain source on SID of CP and AA (n = 12).

[2] Yellow Corn, MKC (Manhattan, KS); White Sorghum, NuLife Market (Scott City, KS); Red Sorghum, MKC (Manhattan, KS).

Table 5. The standardized ileal digestibility (SID) concentration of CP and AA in experimental diets[1,2,3]

Item, %	Corn	White sorghum	Red sorghum	SEM	*P* =
CP	5.71[b]	7.00[a]	7.51[a]	0.304	0.001
Indispensable AA					
Arg	0.31	0.31	0.30	0.009	0.303
His	0.19[a]	0.17[b]	0.18[a]	0.002	0.001
Ile	0.21[c]	0.27[b]	0.30[a]	0.007	0.001
Leu	0.83[c]	0.92[b]	1.13[a]	0.018	0.001
Lys	0.20[a]	0.19[a]	0.16[b]	0.008	0.001
Met	0.14[a]	0.13[b]	0.14[a]	0.002	0.001
Phe	0.32[c]	0.38[b]	0.43[a]	0.008	0.001
Thr	0.19[b]	0.23[a]	0.24[a]	0.009	0.001
Trp	0.04[c]	0.08[a]	0.07[b]	0.001	0.001
Val	0.30[c]	0.36[b]	0.40[a]	0.009	0.001
Total	2.72[c]	3.04[b]	3.32[a]	0.005	0.001
Dispensable AA					
Ala	0.49[c]	0.62[b]	0.76[a]	0.019	0.001
Asp	0.41[b]	0.49[a]	0.52[a]	0.016	0.001
Cys	0.12[xy]	0.12[x]	0.13[y]	0.004	0.095
Glu	1.29[c]	1.53[b]	1.82[a]	0.031	0.001
Gly	0.20	0.22	0.22	0.028	0.295
Ser	0.30[c]	0.33[b]	0.38[a]	0.009	0.001
Tyr	0.18[c]	0.23[b]	0.25[a]	0.074	0.001
Total	3.48[c]	4.19[b]	4.71[a]	0.218	0.001
Total AA	6.17[c]	7.20[b]	8.00[a]	0.276	0.001

a-cMeans within a row lacking a common superscript are different ($P < 0.05$).

[x-y] Means within a row lacking a common superscript tended to differ ($P < 0.10$).

[1] Effect of grain source on SID of CP and AA (n = 12).

[2] Yellow Corn, MKC (Manhattan, KS); White Sorghum, NuLife Market (Scott City, KS); Red Sorghum, MKC (Manhattan, KS).

[3] Values for SID concentration were calculated by multiplying the analyzed CP and AA content by the determined SID coefficient.