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Reducing dietary protein in corn–soybean meal diets by reducing soybean meal and adding synthetic amino acids does not affect net energy or ileal starch digestibility, but increases ileal amino acid digestibility and reduces nitrogen retention

Minoy Cristobal[1], Su A. Lee[1], Carl M. Parsons[1], and Hans H. Stein*[,1]

[1]Department of Animal Sciences, University of Illinois, Urbana, IL 61801, United States
*Corresponding author. Email: hstein@illinois.edu

Abstract

Two experiments were conducted to test the hypothesis that diet protein concentration does not affect apparent ileal digestibility (AID) of starch, standardized ileal digestibility (SID) of amino acids (AA), daily nitrogen retention, or net energy (NE) in diets fed to growing pigs. In experiment 1, seven diets were used. A corn-SBM diet without synthetic AA was formulated to contain 17% CP. Five additional diets containing 14, 13, 12, 11, or 10% CP were formulated by reducing SBM and increasing corn and synthetic AA. A nitrogen-free diet was also used to determine basal endogenous losses of AA, and Cr_2O_3 was included in all diets as an indigestible marker. Seven barrows (initial body weight: 38.2 ± 1.5 kg) that had a T-cannula installed in the distal ileum were allotted to a 7 × 7 Latin square design with seven diets and seven periods, and ileal digesta were collected for 2 d of each period. Results demonstrated that AID of starch was not influenced by diet CP concentration, but SID of CP and all indispensable and dispensable AA increased (linear, $P < 0.05$) as dietary CP was reduced. In experiment 2, the six protein-containing diets from experiment 1 were used, but Cr_2O_3 was replaced by corn and no nitrogen-free diet was used in this experiment. Twenty-four growing pigs (initial body weight: 29.9 ± 2.4 kg) were placed in six calorimeter chambers with four pigs per chamber. The six chambers were allotted to the six diets using a 6 × 6 Latin square design with six periods of 14 d. Pigs had ad libitum access to diets throughout the experiment except during the final 36 h of each period, when pigs were fasted. Net energy in diets was determined using indirect calorimetry. Results demonstrated that digestible energy, metabolizable energy, and daily nitrogen retention were reduced (linear, $P < 0.05$) as dietary CP was reduced, but NE in diets was not influenced by dietary CP. In conclusion, the hypothesis that reducing CP of diets for pigs by reducing SBM and increasing corn and synthetic AA does not affect AID of starch or NE of diets was confirmed, but the hypothesis that SID of indispensable AA and daily nitrogen retention are not affected by dietary protein concentration was rejected.

Lay Summary

Two experiments were conducted to determine effects of reducing dietary crude protein by replacing soybean meal with corn and synthetic amino acids on ileal digestibility of starch and amino acids, daily nitrogen retention, and net energy in diets fed to growing pigs. In both experiments, pigs were fed diets with 17%, 14%, 13%, 12%, 11%, or 10% crude protein, with synthetic amino acids and corn replacing dietary soybean meal as dietary protein was reduced. Results indicated that reducing protein in the diet did not affect ileal digestibility of starch but increased the digestibility of protein and amino acids. However, digestible energy was reduced as dietary protein level was reduced, but there were no differences in net energy among diets. Results demonstrated that reducing dietary protein by reducing the level of soybean meal and increasing corn and synthetic amino acids does not influence the net energy of diets, which indicates that the net energy of soybean meal is likely close to the net energy of corn.

Keywords low protein, net energy, nitrogen retention, pigs, soybean meal, synthetic amino acids

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Abbreviations: AA, amino acids; ADF, acid detergent fiber; AEE, acid-hydrolyzed ether extract; AID, apparent ileal digestibility; ATTD, apparent total tract digestibility; CP, crude protein; DE, digestible energy; DM, dry matter; FHP, fasting heat production; GE, gross energy; IDF, insoluble dietary fiber; ME, metabolizable energy; NE, net energy; RQ, respiratory quotient; SBM, soybean meal; SDF, soluble dietary fiber; SID, standardized ileal digestibility; TDF, total dietary fiber; THP, total heat production

Introduction

Soybean meal (SBM) is the major source of amino acids (AA) in diets for pigs in most regions of the world. In the United States, around 18% of all SBM produced is used to feed pigs (Soybean Meal Info Center 2022). However, due to the increased usage of feed-grade synthetic AA and distillers dried grains with solubles, it is estimated that SBM usage by pigs has been reduced over the last 25 years, particularly in countries that do not produce SBM (Van Heugten et al. 2021; Pope et al. 2023). Also, reducing crude protein (CP) in diets, which requires a reduction in SBM, has been proposed as a method to reduce the environmental impact of swine production by reducing nitrogen excretion and carbon footprint (Eugenio et al. 2022).

Corn and SBM are assumed to have concentrations of metabolizable energy (ME) that are not different, but corn is believed to contain more net energy (NE) than SBM (NRC 2012). Therefore, in theory, corn-SBM diets formulated with synthetic AA contain more NE than corn-SBM diets without synthetic AA because if synthetic AA are used, the inclusion of SBM is reduced and the inclusion of corn is increased. However, recent data indicate that diets based primarily on corn and SBM without synthetic AA contain more NE than diets based on corn and synthetic AA, which indicates that NE of SBM may have been underestimated (Cemin et al. 2020). Likewise, recent data from indirect calorimetry experiments (Li et al. 2017; Lee et al. 2021) indicate that the NE in SBM is greater than current book values (Sauvant et al. 2004; NRC 2012; Rostagno et al. 2024). The NE of SBM calculated from the feed efficiency of growing pigs was also greater than current book values (Ibagon et al. 2025). Thus, results of a number of recent experiments indicate that NE in SBM is likely underestimated, but it is not known by how much and how this likely underestimation impacts the NE of diets with varying concentrations of corn and SBM.

Synthetic AA are expected to be completely digestible (Oliveira et al. 2020) and to be absorbed at a faster rate compared with intact protein (Kodera et al. 2006). Thus, corn-SBM diets with different inclusions of synthetic AA may have variations in digestibility and absorption rates of AA, which may cause AA imbalances at sites of protein synthesis and affect the metabolism of AA in the diet (Trottier 2006; Selle et al. 2020; Eugenio 2022). It is also possible that an asynchrony of absorbed carbohydrates and AA may occur, causing a mismatch between nitrogen and energy supply, increasing the oxidation of the rapid absorbed AA (van den Borne et al. 2007). This may reduce the amount of protein being synthesized and, therefore, also reduce daily nitrogen retention. However, it is not known how this may impact NE of diets in which some of the SBM is replaced by synthetic AA. Likewise, if diets contain less SBM and more corn, the concentration of starch will increase, but it is not known if increased dietary starch will affect ileal digestibility of starch.

Therefore, two experiments were conducted to test the hypothesis that replacing SBM with corn and synthetic AA does not affect the standardized ileal digestibility (SID) of AA and CP, apparent ileal digestibility (AID) of starch, nitrogen retention, or NE in diets fed to growing pigs.

Materials and methods

Two experiments were conducted, and the protocols for both experiments were reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois before animal work was initiated. Pigs were the offspring of Line 800 boars and Camborough females (Pig Improvement Company, Hendersonville, TN, USA).

Dietary treatments

In experiment 1, seven diets were used. A diet that contained corn, SBM, and no synthetic AA was formulated to contain 17% CP (Table 1). Five additional diets were formulated to contain 14, 13, 12, 11, or 10% CP, respectively, and these diets contained more corn and less SBM than the 17% CP diet, but synthetic AA were gradually included as CP was reduced. All diets were formulated to maintain a constant ratio of total Ca to standardized total tract digestible P of 2.1:1 (NRC 2012). A nitrogen-free diet was used to determine basal endogenous losses of AA and CP. All seven diets contained 0.40% chromic oxide as an indigestible marker. All diets, except for the nitrogen-free diet, were formulated to meet or exceed current requirements for SID AA, and all diets met requirements for vitamins and minerals by growing-finishing pigs (NRC 2012). In experiment 2, six diets that were identical to the six protein-containing diets used in experiment 1 were used, but no nitrogen-free diet was included in experiment 2, and chromic oxide was replaced by corn.

Animals, housing, and feeding

In experiment 1, seven barrows (average initial body weight: 38.2 ± 1.5 kg) were allotted to a 7 × 7 Latin square design with seven diets and seven periods (Kim and Stein 2009). Thus, there were seven replicate pigs per diet. Pigs had a T-cannula installed in the distal ileum for collection of ileal digesta (Stein et al. 1998). Pigs were housed in individual pens (1.2 × 1.5 m) in an environmentally controlled room with the ambient temperature maintained between 20 and 24 °C. Pens had smooth sides and fully slatted tribar floors and were equipped with a feeder and a nipple waterer. Pigs had free access to water throughout the experiment. Feed allowance was calculated as 3.0 times the maintenance requirement for ME (ie 197 kcal ME per kg body weight$^{0.60}$; NRC 2012) and was adjusted according to the body weight of pigs at the beginning of each period.

In experiment 2, 24 barrows (average initial body weight: 29.3 ± 2.3 kg) were allotted to the six diets in a 6 × 6 Latin square design with 6 indirect calorimetry chambers and six consecutive periods (Munoz Alfonso et al. 2026). Thus, there were six

Table 1 Ingredient and nutrient composition of experimental diets, experiment 1.[1]

Item[2]	Dietary crude protein						
	17%	14%	13%	12%	11%	10%	N-free[2]
Corn, yellow dent	69.28	76.68	78.94	81.19	83.35	85.42	-
Soybean meal, dehulled, solvent extracted	26.97	19.10	16.65	14.20	11.76	9.34	-
Soybean oil	1.00	1.00	1.00	1.00	1.00	1.00	4.00
Dicalcium phosphate	0.73	0.86	0.90	0.94	0.98	1.03	1.75
Ground limestone	0.73	0.70	0.70	0.69	0.68	0.68	0.30
Cornstarch	-	-	-	-	-	-	68.15
Sugar	-	-	-	-	-	-	20.00
Magnesium oxide	-	-	-	-	-	-	0.10
Potassium carbonate	-	-	-	-	-	-	0.40
L-Lys-HCl, 78% Lys	-	0.22	0.30	0.37	0.45	0.53	-
DL-Met, 98% Met	-	0.08	0.10	0.13	0.15	0.17	-
L-Thr, 98% Thr	-	0.07	0.10	0.13	0.17	0.20	-
L-Trp, 98% Trp	-	-	0.01	0.03	0.04	0.05	-
L-Val, 98% Val	-	-	-	0.03	0.07	0.12	-
L-Ile, 98% Ile	-	-	-	-	0.02	0.06	-
L-Phe, 98% Phe	-	-	-	-	0.01	0.06	-
L-His, 98% His	-	-	-	-	0.02	0.04	-
Solka floc[3]	-	-	-	-	-	-	4.00
Sodium chloride	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Chromic oxide	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[4]	0.50	0.50	0.50	0.50	0.50	0.50	0.50

[1] Diets in experiment 2 were identical to those used in experiment 1 with the exception that 0.40% chromic oxide was replaced by corn and no nitrogen-free diet was used.

[2] Nitrogen-free diet

[3] International Fiber Corporation, Urbana, OH, USA.

[4] The vitamin-mineral premix provided the following quantities of vitamins and micro-minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,150 IU; vitamin D_3 as cholecalciferol, 2,210 IU; vitamin E as $_{DL}$-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfate, 1.42 mg; thiamin as thiamine mononitrate, 1.10 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 1.00 mg; vitamin B_{12}, 0.03 mg; $_D$-pantothenic acid as $_D$-calcium pantothenate, 23.6 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper chloride; Fe, 125 mg as iron sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese hydroxychloride; Se, 0.30 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc hydroxychloride.

replicate calorimetry chambers per diet, and all diets were provided to each chamber during one period. Four barrows were placed in each chamber. Each chamber was equipped with a stainless steel wet-dry feeder, and a nipple waterer was available to ensure free access to water throughout the experiment. Each chamber was also equipped with a fully slatted T-bar floor, stainless steel fecal screens, and urine pans, which allowed for total, but separate, collection of feces and urine. The temperature and relative humidity inside the chambers were maintained at 23 °C and 55%, respectively, and controlled by a temperature and humidity control unit (Model 9241-2220-B1D0000; Parameter Generation & Control, Parameter, Black Mountain, NC, USA). The air velocity was maintained at 1.13 m^3/min using an airflow meter (AccuValve; Accutrol, LLC, Danbury, CT, USA). Diets were fed for 12.5 d on an ad libitum basis, but in the morning of d 14, feeders were emptied, and pigs were fasted during the following 36 h.

Sample collection

In experiment 1, each period lasted 7 d, where the initial 5 d were considered an adaptation period to the diet, and ileal digesta were collected on d 6 and 7 for 9 h each day (from 0700 to 1600 h) following standard procedures (Stein et al. 1998). A plastic bag was attached to the opened cannula barrel using a plastic cable tie, and digesta flowing into the bag were collected. Bags were replaced once they were filled with digesta or at least every 30 min and immediately stored at −20 °C to prevent bacterial degradation of AA in the digesta. At the conclusion of the experiment, ileal digesta samples were thawed, mixed, and a subsample was collected, lyophilized (Lagos and Stein 2019), and finely ground in preparation for chemical analysis.

In experiment 2, diets were fed for 12.5 d, during which feed intake was not restricted. The initial 6.5 d were considered the adaptation period to the diet starting from midday on d 1. At 0700 h on d 8, the gas analyzers (Classic Line, Sable System Int., North Las Vegas, NV, USA) were turned on to measure O_2 consumption and CO_2 and CH_4 productions, and gas measurements ceased at 0700 h on d 14. Gas measurements were used to determine total heat production (THP). Feces and urine were quantitatively collected from the screens and pans beneath each chamber from d 8 to 13. At 0700 h on d 14, pigs were deprived of feed for 36 h. This time was considered the fasting period, and the initial 24 h of fasting were considered the time when the animals digested and metabolized the remaining feed in the intestinal tract to produce energy. However, the following 12 h of fasting were considered the period when the animals mobilized endogenous nutrients to produce energy, and the fasting heat production (FHP) was measured during this period (De Lange et al. 2006). Fasting heat production was calculated using urine nitrogen, measured O_2 consumption, and CO_2 and CH_4 production during this period.

All pigs were weighed prior to being moved into the calorimeter chambers and at the conclusion of each collection period. Chambers were opened every day to add feed to the feeders and to collect feces and urine during collection periods. Feed spillage on the screens was collected daily during the collection period, and the weight of spilled feed was recorded to determine feed intake. To avoid nitrogen loss from the urine, 50 mL of 6 *N* HCl was added to each urine pan every day during the collection period. Collected feces were dried immediately after collection in a 65 °C forced air drying oven (Thermo Fisher Scientific Inc.; model Heratherm OMH750, Waltham, MA, USA) until constant weight and then ground through a 1-mm screen using a hammer mill (model: MM4; Schutte Buffalo, NY, USA). Collected urine was weighed and mixed, and 10% was stored at −20 °C immediately after collection. At the end of the experiment, urine samples were thawed and mixed within chamber and period, and two subsamples were collected and stored at −20 °C. One subsample was thawed and dripped on cotton balls placed in a plastic bag, then lyophilized (Kim et al. 2009). The other subsample was thawed and used for nitrogen analysis. However, urine collected during the fasting period was only analyzed for nitrogen. Data from the gas analyzers obtained during the period that the chambers were open and until they reached the condition set by the temperature and humidity control unit were disregarded for the final calculation of heat production.

Chemical analysis

In experiment 1, diet and lyophilized ileal digesta samples were analyzed for dry matter (DM; method 930.15; AOAC Int., 2019), and nitrogen was analyzed using the combustion procedure (method 990.03; AOAC Int., 2019) on a LECO FP628 (LECO Corp., Saint Joseph, MI, USA). Crude proein in diets and ileal digesta samples was calculated as analyzed nitrogen × 6.25. Diet and ileal digesta samples were analyzed for AA (method 982.30 E [a, b, c]; AOAC Int., 2019) at the Agricultural Experiment Station Chemical Laboratories at the University of Missouri (Columbia, MO, USA) on a Hitachi AA analyzer (Model No. L8800; Hitachi High Technologies America, Inc., Pleasanton, CA, USA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard. Diet and ileal digesta samples were also analyzed for starch using the glucoamylase procedure (method 979.10; AOAC Int., 2019), and for chromium using Inductive Coupled Plasma Atomic Emission Spectrometry (method 990.08 AOAC Int., 2019).

In experiment 2, diet and ground fecal samples were analyzed for DM and nitrogen as described for experiment 1. Nitrogen and AA in diets were also analyzed as described for experiment 1, and CP was calculated as nitrogen × 6.25. Diet samples were analyzed for ash (method 942.05; AOAC Int., 2019), and diet, fecal, and lyophilized urine samples were analyzed for gross energy (GE) using bomb calorimetry (Model 6400; Parr Instruments, Moline, IL, USA). Urine samples that were not lyophilized were analyzed for nitrogen using the Kjeldahl method (method 984.13; AOAC Int., 2019) on a Kjeltec 8400 (FOSS Inc., Eden Prairie, MN, USA). Acid-hydrolyzed ether extract (AEE) in diet and fecal samples was analyzed using acid hydrolysis with 3 *N* HCl (Ankom HCl Hydrolysis System, Ankom Technology, Macedon, NY, USA) followed by fat extraction using petroleum ether (method 2003.06, AOAC Int., 2019; Ankom XT-15 Extractor, Ankom Technology, Macedon, NY, USA). Insoluble dietary fiber (IDF) and soluble dietary fiber (SDF) were also analyzed in diets and fecal samples on an Ankom Total Dietary Fiber Analyzer (Ankom Technology, Macedon, NY, USA) using method 991.43 (AOAC Int., 2019). Total dietary fiber (TDF) was calculated as the sum of IDF and SDF. Diets were also analyzed for acid detergent fiber (ADF; method 12; Ankom 2000 Fiber Analyzer, Ankom Technology, Macedon, NY, USA).

The same batches of corn and SBM were used in experiments 1 and 2. Samples were analyzed for DM, GE, AEE, IDF, SDF, ash, ADF, AA, starch, and nitrogen as described for experiment 2. Crude protein and TDF for corn and SBM were also calculated as described for experiment 2. Soybean meal was also analyzed for trypsin inhibitors (method Ba 12-75; AOCS 2006).

Calculations

In experiment 1, AID of CP, AA, and starch was calculated using analyzed CP, AA, starch, and Cr in diets and ileal digesta (Stein et al. 2007). The basal endogenous losses of CP and AA were calculated from pigs fed the nitrogen-free diet, and SID of CP and AA was calculated by correcting the AID for the basal endogenous losses of CP and AA (Stein et al. 2007).

In experiment 2, the apparent total tract digestibility (ATTD) of GE, DM, TDF, and AEE was calculated for each diet (Adeola 2001), and digestible energy (DE) and ME in each diet were calculated as well (NRC 2012). Nitrogen intake, nitrogen excretion, ATTD of nitrogen, retention of nitrogen, and biological value were also calculated (Pedersen et al. 2007).

For calculation of NE in diets, concentrations of O_2, CO_2, and CH_4 were averaged separately for the fed period and for the last 12 h of the fasting period. The respiratory quotient (RQ) was calculated as the ratio between CO_2 production (L/d) and O_2 consumption (L/d; Richardson 1929). THP was calculated from gas exchanges during the fed period using the following equation (Brouwer 1965):

$$\mathrm{THP_{kcal}} = [(3.866 \times \ \mathrm{O_2}) + (1.200 \times \ \mathrm{CO_2}) - (0.518 \times \ \mathrm{CH_4}) - (1.431 \times \mathrm{urine\ \ nitrogen})],$$

where O_2, CO_2, and CH_4 were expressed as L, and urine nitrogen was expressed as g. The FHP measured during the fasting period was calculated as described for THP. Heat increment was calculated by subtracting FHP from THP, and NE in each diet was calculated using the following equation (modified from NRC 2012):

$$\mathrm{NE_{kcal/kg}} = \frac{\mathrm{ME} - (\mathrm{THP} - \mathrm{FHP})}{\mathrm{feed\ \ intake}},$$

where ME is in kcal/kg, THP and FHP are in kcal/kg, and feed intake is in kg and refers to feed intake during the collection period. The NE of diets was also calculated (Table 2) using the published NE values for yellow dent corn, dehulled solvent-extracted SBM, and soybean oil (NRC 2012). Net energy from synthetic AA was also included in the calculation and assumed to be 80% of their respective GE because synthetic AA are 100% digestible (Oliveira et al. 2020) and a NE: DE ratio of 80% was assumed due to an assumed lower heat increment associated with synthetic AA than with other nutrients. In addition, NE in each diet was also calculated using equations 1–7 (NRC 2012).

Statistical analysis

Data from both experiments were analyzed using the MIXED procedure in SAS (version 9.4; SAS Inst. Inc., Cary, NC, USA). Homogeneity of the variances among treatments was confirmed using the UNIVARIATE procedure. The MIXED procedure in SAS was used to generate studentized residuals, and outliers were defined as means with residuals greater than 3 or less than −3. However, no outliers were detected in either of the two experiments. For experiment 1, the statistical model included diet as the fixed effect and period and animal as random effects. The pig was the experimental unit. For experiment 2, the statistical model included diet as the fixed effect and chamber and period as random effects. The calorimeter chamber was the experimental unit. For both experiments, least squares means were calculated, and contrast coefficients were generated from analyzed dietary CP using the Interactive Matrix Language procedure of SAS to account for unequal spacing among treatments. These coefficients were used to determine linear and quadratic effects of reducing dietary CP from 17 to 10%. The coefficients used for the linear contrast were 0.750, 0.210, 0.030, −0.150, −0.330, and −0.510, and for the quadratic contrast coefficients were 0.496, −0.436, −0.427, −0.259, 0.069, and 0.557. Statistical significance and tendency were considered at $P < 0.05$ and $0.05 \leq P < 0.10$, respectively.

Results

Pigs remained healthy during both experiments, and no feed refusals were observed. All animals completed the experiments, and no mortalities were observed. Analyzed concentrations of nutrients in diets (Tables 2 and 3) were in agreement with calculated values.

Experiment 1

Results indicated that there was no effect of reducing dietary CP from 17% to 10% on AID of CP, total dispensable AA, total AA, or starch (Table 4). The AID of Lys, Met, Thr, Trp, Glu, and total indispensable AA increased (linear, $P < 0.05$) as dietary CP was reduced, and the AID of His, Leu, and Val tended to increase (linear, $P < 0.10$) as CP was reduced. However, the AID of Arg decreased (linear, $P < 0.01$) as dietary CP was reduced.

Reducing CP in diets increased SID of CP and of each indispensable and dispensable AA (linear, $P < 0.05$; Table 5). Likewise, when determining the SID of total indispensable or total dispensable AA, an increasing effect (linear, $P < 0.01$) was observed when reducing dietary CP.

Experiment 2

Reducing dietary CP tended to increase (linear, $P < 0.10$) feed intake and ATTD of DM (Table 6), but reducing CP reduced (linear, $P < 0.05$) ATTD of TDF, DE, and ME in diets. However, reducing dietary CP did not affect the ATTD of AEE, ATTD of GE, daily fecal GE excretion, daily urine GE excretion, daily THP, daily FHP, daily retained energy, RQ during fasted or fed state, or NE in diets. The ME: DE, NE: DE, and NE: ME tended to increase (linear, $P < 0.1$) when dietary CP was reduced.

Reducing dietary CP decreased (linear, $P < 0.01$) daily nitrogen intake, daily nitrogen excreted in feces or in urine, daily absorbed nitrogen, and daily retained nitrogen (Table 7). Likewise, reducing dietary CP decreased (quadratic, $P < 0.01$) the ATTD of nitrogen. However, reducing dietary CP increased (linear, $P < 0.05$) nitrogen retention as a percent of intake and also reduced the biological value of CP.

Discussion

The analyzed concentrations of nutrients in corn and SBM were consistent with published values (NRC 2012), and analyzed CP and total AA in diets were in agreement with formulated values, indicating accurate diet preparation. Analyzed starch increased as dietary CP decreased due to greater corn inclusion. In contrast, analyzed indispensable AA decreased with reduced CP because SBM was replaced with synthetic AA. Therefore, less total indispensable AA were required to meet SID AA requirements. The concentration of Met increased as dietary CP was reduced because additional synthetic Met was included to compensate for reduced Cys from SBM.

Experiment 1

The AID of starch in all diets agreed with previous data (Lin et al. 1987; Bach Knudsen et al. 2006; McGhee and Stein 2020; Lee et al. 2025). Starch is digested to glucose and absorbed in the small intestine; therefore, determining ileal digestibility of starch yields a more accurate digestibility estimate compared with total tract digestibility (Stein and Bohlke 2007). Because SBM is not a significant source of starch, the digestibility of starch in the diets reflects the digestibility of starch in corn. The observation that an increase in dietary starch from 45% to approximately 55% did not impact AID of starch demonstrates that pigs digest starch very efficiently, even at high inclusion levels (Cervantes-Pahm et al. 2014).

The AID and SID of CP and AA in the 17% CP diet agreed with values reported for corn–SBM diets without synthetic AA fed to growing pigs (Urriola and Stein 2010). Soybean meal was the primary source of Lys in the 17% CP diet (26.97% SBM and no supplemental Lys), whereas in the 10% CP diet, SBM inclusion was reduced to 9.34% and 0.53% L-Lys-HCl was added, indicating that a substantial proportion of Lys was supplied by synthetic AA, with smaller contributions from SBM and corn. Although the SID of AA in SBM is greater than in corn (NRC 2012), the increased SID of AA as dietary CP was reduced was expected because synthetic AA are highly digestible and rapidly absorbed (Chung and Baker 1992; Trottier 2006; Selle et al. 2020). Increased SID of AA was observed when synthetic AA were

Table 2 Analyzed nutrient composition of diets, as-fed basis, experiment 1.

Item	Dietary crude protein						
	17%	14%	13%	12%	11%	10%	N-free[1]
Dry matter, %	87.19	86.91	86.71	86.80	86.88	87.51	92.15
Crude protein, %	18.66	13.77	13.31	13.10	11.36	10.65	0.61
Starch, %	45.00	45.60	47.70	52.50	51.80	55.20	56.90
Indispensable amino acids, %							
Arg	1.24	0.85	0.78	0.80	0.62	0.58	0.01
His	0.50	0.36	0.34	0.35	0.31	0.31	0.01
Ile	0.88	0.61	0.56	0.57	0.47	0.47	0.01
Leu	1.62	1.23	1.16	1.16	1.02	0.98	0.02
Lys	1.07	0.91	0.89	0.88	0.88	0.86	0.02
Met	0.27	0.25	0.33	0.30	0.30	0.32	0.01
Phe	0.98	0.69	0.64	0.65	0.54	0.55	0.01
Thr	0.72	0.55	0.64	0.61	0.51	0.58	0.01
Trp	0.18	0.14	0.14	0.14	0.14	0.13	0.02
Val	0.92	0.66	0.61	0.64	0.60	0.57	0.01
Total	8.38	6.25	6.09	6.10	5.39	5.35	0.13
Dispensable amino acids, %							
Ala	0.93	0.72	0.68	0.63	0.61	0.59	0.02
Asp	1.98	1.34	1.23	1.20	0.97	0.89	0.02
Cys	0.30	0.21	0.22	0.20	0.18	0.17	0.00
Glu	3.40	2.44	2.25	2.22	1.89	1.78	0.03
Gly	0.80	0.57	0.53	0.54	0.44	0.42	0.01
Pro	1.08	0.84	0.80	0.80	0.70	0.60	0.04
Ser	0.83	0.61	0.56	0.57	0.47	0.45	0.02
Tyr	0.64	0.46	0.43	0.44	0.35	0.33	0.01
Total	9.96	7.19	6.70	6.60	5.61	5.23	0.15
Total amino acids	18.34	13.44	12.79	12.70	11.00	10.58	0.28

[1] Nitrogen-free diet.

added to corn-based diets (Oliveira et al. 2020), indicating that the increased inclusion of synthetic AA contributed to the observed response in SID of AA.

The decrease in AID of Arg as dietary CP was reduced, despite an increase in SID of Arg, is likely due to a greater relative contribution of endogenous Arg losses at lower dietary Arg concentrations. As SBM was reduced and corn inclusion increased, dietary Arg decreased while endogenous losses remained constant, reducing AID values. However, after correcting for endogenous losses, SID of Arg increased, indicating improved true digestibility, likely due to reduced dietary fiber. However, the increase in SID of AA that was not supplemented as synthetic AA indicates that additional factors contributed to this increase. One such factor is the reduction in TDF as SBM was replaced by corn because fiber has negative effects on AA digestibility and may limit enzyme access to protein (Gutierrez et al. 2013). Differences in protein structure and storage between SBM and corn may also have contributed to the observed response. Proteins in SBM are primarily stored as globulins (glycinin and β-conglycinin) within protein bodies associated with cell wall structures rich in insoluble fiber, which may restrict enzyme access (NRC 2012; Rojas and Stein 2013). In contrast, proteins in corn are mainly prolamins (zeins) embedded in a starch–protein matrix in the endosperm, and digestion of starch may increase accessibility of these proteins to digestive enzymes (Bach Knudsen et al. 2006; Cervantes-Pahm et al. 2014). Therefore, differences in the physical association of proteins with fiber in SBM and with starch in corn may influence protein hydrolysis and AA digestibility. Other possible factors include lower concentrations of antinutritional factors and differences in absorption kinetics between synthetic and protein-bound AA, which may influence AA transport and utilization due to shared intestinal transport systems (Trottier 2006; Selle et al. 2020).

Experiment 2

The observed results for feed intake and daily fecal and urine GE excretion agreed with data from group-housed pigs fed corn-SBM diets (Lee et al. 2024). The ATTD of DM, AEE, TDF, and GE also agreed with previous data (Urriola and Stein 2010; Liu et al. 2019; Rodriguez et al. 2020). Soybean meal and corn both have ATTD of DM around 90% (Li et al. 2017; Navarro et al. 2018). Therefore, the observation that there were no effects of replacing SBM with corn on ATTD of DM was expected. The lack of effects of dietary treatment on ATTD of AEE when replacing SBM by corn indicates that there is no difference between corn and SBM in how AEE is digested by growing pigs.

Table 3 Analyzed and calculated nutrient composition of ingredients and diets, as-fed basis, experiment 2.

Item	Corn	SBM[1]	Dietary crude protein					
			17%	14%	13%	12%	11%	10%
Calculated values								
Metabolizable energy, kcal/kg[2]	3,395	3,294	3,340	3,332	3,328	3,323	3,316	3,307
Net energy, kcal/kg[2]	2,672	2,087	2,500	2,548	2,564	2,580	2,598	2,617
Net energy, kcal/kg[3]	2,743	2,077	2,550	2,555	2,573	2,600	2,603	2,629
Analyzed values								
Dry matter, %	86.09	88.71	87.01	87.09	86.94	86.81	86.89	86.91
Gross energy, kcal/kg	3,821	4,209	3,845	3,801	3,800	3,788	3,785	3,786
Crude protein, %	6.45	46.80	17.97	14.31	13.11	11.89	11.56	10.57
Acid-hydrolyzed ether extract, %	2.53	1.07	2.55	2.60	2.80	2.77	2.51	2.56
Starch, %	64.50	2.30	45.00	45.60	47.70	52.50	53.80	55.20
Ash	1.32	6.22	4.27	4.21	4.13	4.08	4.06	4.01
Ca	0.02	0.33	0.58	0.56	0.59	0.55	0.57	0.59
P	0.26	0.71	0.51	0.49	0.51	0.48	0.48	0.52
Total dietary fiber	10.70	17.10	11.80	10.50	10.60	10.00	10.20	9.90
Soluble dietary fiber	ND[4]	2.30	ND[4]	ND[4]	ND[4]	0.90	0.30	1.40
Insoluble dietary fiber	10.70	14.80	11.80	10.50	10.60	9.10	9.90	8.50
Acid detergent fiber	2.88	5.28	4.00	3.82	3.73	3.67	3.61	3.16
Indispensable amino acids, %								
Arg	0.32	3.33	1.14	0.90	0.79	0.69	0.67	0.55
His	0.19	1.23	0.47	0.38	0.35	0.31	0.31	0.29
Ile	0.25	2.31	0.77	0.60	0.55	0.48	0.48	0.49
Leu	0.76	3.65	1.48	1.26	1.16	1.05	1.05	0.96
Lys	0.24	2.95	1.01	0.96	0.92	0.87	0.87	0.88
Met	0.13	0.64	0.24	0.27	0.28	0.27	0.26	0.31
Phe	0.32	2.41	0.88	0.70	0.64	0.57	0.57	0.54
Thr	0.24	1.81	0.68	0.60	0.56	0.57	0.57	0.61
Trp	0.05	0.63	0.20	0.17	0.17	0.16	0.14	0.14
Val	0.32	2.34	0.87	0.70	0.64	0.60	0.63	0.61
Total	2.82	21.30	7.74	6.54	6.06	5.57	5.54	5.38
Dispensable amino acids, %								
Ala	0.48	2.03	0.87	0.76	0.69	0.64	0.64	0.58
Asp	0.45	5.33	1.78	1.38	1.23	1.08	1.03	0.86
Cys	0.14	0.64	0.27	0.23	0.21	0.18	0.19	0.18
Glu	1.20	8.51	3.17	2.57	2.32	2.05	2.01	1.75
Gly	0.27	1.96	0.73	0.60	0.53	0.48	0.47	0.40
Pro	0.56	2.37	0.98	0.84	0.78	0.72	0.66	0.60
Ser	0.30	1.97	0.78	0.65	0.56	0.51	0.50	0.43
Tyr	0.20	1.69	0.59	0.47	0.44	0.38	0.37	0.33
Total	3.60	24.50	9.17	7.50	6.76	6.04	5.87	5.13
Total amino acids	6.42	45.80	16.91	14.04	12.82	11.61	11.41	10.51

[1] Trypsin inhibitor units per mg: 3.42.

[2] Calculated using published metabolizable energy or net energy values for yellow dent corn and dehulled, solvent-extracted SBM (NRC 2012), and an estimated net energy of each synthetic indispensable amino acid that on average was 4,556 kcal/kg. The values for corn, soybean meal, and synthetic amino acids were multiplied by their respective inclusion rate in the diet to obtain the calculated total metabolizable or net energy of the diet. For synthetic amino acids, net energy values were assumed to be 80% of gross energy (Boisen and Verstegen 2000).

[3] Calculated with published equation (equations 1–7; NRC 2012) to predict net energy in diets from analyzed nutrient composition and the determined metabolizable energy from experiment 2. The equation yielded net energy values as kcal/kg of dry matter but were then adjusted to 90% dry matter.

[4] Not detectable.

Soybean meal contains more TDF and IDF, and slightly more SDF, than corn (NRC 2012; Navarro et al. 2018; Abelilla and Stein 2019; Rodriguez et al. 2020). These differences in TDF were also observed in the analyzed composition of corn and SBM in the present experiment. The fact that the ATTD of TDF decreased as SBM was replaced by corn indicates a greater digestibility of TDF in SBM compared with corn, which may be because there is more SDF in SBM than in corn. Differences in ATTD of TDF or IDF caused by varying inclusion of ingredients in diets have been previously reported (Abelilla and Stein 2019). The decrease in ATTD of TDF as dietary CP was reduced may decrease ATTD of GE due to reduced energy derived from fiber fermentation

Table 4 Apparent ileal digestibility (AID) of crude protein, starch, and amino acids (AA),[1] experiment 1.

Item	Dietary crude protein							Contrast *P*-value	
	17%	14%	13%	12%	11%	10%	SEM	Linear[2]	Quadratic[2]
Crude protein	76.8	77.1	76.0	79.6	76.9	78.3	1.32	0.242	0.671
Starch	94.1	95.5	95.6	95.2	95.3	94.9	0.53	0.319	0.419
Indispensable AA									
Arg	87.0	85.5	84.1	86.6	83.6	84.7	0.93	0.006	0.410
His	81.2	81.7	79.8	82.3	82.2	83.2	0.82	0.088	0.106
Ile	81.1	80.1	78.5	81.5	78.9	80.5	0.84	0.413	0.223
Leu	81.4	82.3	81.3	83.6	82.3	82.9	0.79	0.085	0.920
Lys	75.4	77.4	76.6	81.4	80.4	81.1	0.96	<0.001	0.463
Met	84.5	87.0	89.6	89.0	90.0	90.7	0.57	<0.001	0.282
Phe	81.4	81.4	80.1	82.7	80.6	82.9	0.77	0.292	0.136
Thr	71.1	72.5	76.6	78.3	75.7	79.9	1.00	<0.001	0.645
Trp	78.3	81.5	81.2	82.3	84.4	84.9	0.91	<0.001	0.632
Val	79.5	78.9	77.0	80.7	80.9	81.1	0.85	0.068	0.274
Total	80.4	80.6	80.0	82.7	81.4	82.6	0.76	0.014	0.267
Dispensable AA									
Ala	75.5	75.2	74.1	78.1	74.9	75.3	1.24	0.854	0.920
Asp	76.1	76.2	75.0	78.5	75.4	76.0	0.93	0.873	0.728
Cys	69.5	70.3	70.7	71.5	71.5	71.4	1.24	0.121	0.876
Glu	81.1	83.2	82.7	84.6	83.1	83.9	0.86	0.004	0.195
Gly	61.2	59.3	56.6	62.4	56.2	59.5	3.35	0.432	0.597
Pro	54.2	47.7	41.8	58.3	42.0	48.7	11.61	0.569	0.674
Ser	76.8	77.2	76.0	78.6	75.8	77.3	0.99	0.836	0.961
Tyr	80.4	80.3	78.9	81.8	78.4	79.2	0.76	0.171	0.498
Total	74.3	74.0	72.3	76.9	72.4	74.0	2.00	0.832	0.974
Total AA	76.8	77.1	76.0	79.6	76.9	78.3	1.31	0.242	0.671

[1] Each least squares means represents 7 observations.

[2] Linear or quadratic effects of reducing dietary protein from 17% to 10%.

(Abelilla and Stein 2019). However, because starch increased as CP was reduced, no overall effect of diet composition on ATTD of GE was observed. Differences in fermentability among fiber fractions may result in variation in short-chain fatty acid production and energy yield, which may contribute to differences in energy utilization among diets.

The values for THP, FHP, and RQ in fed and fasted states agreed with data for corn-SBM diets that were determined in the same facility (Muñoz Alfonso 2020; Ibagon et al. 2024; Lee et al. 2024). However, THP and FHP were greater compared with data obtained with individually housed pigs, although the RQ in fed or fasted states observed in this experiment were close to reported data (Noblet et al. 1994; Li et al. 2017; Kim et al. 2018; Lyu et al. 2023). Nonetheless, it appears that THP or FHP were consistent among diets, indicating that there is no influence of dietary CP on THP or FHP. The greater THP in the present experiment compared with previous data is likely due to the ad libitum feeding and that pigs were group-housed in this experiment, whereas restricted feeding and individually housed pigs were used in previous experiments. Therefore, the estimates for THP and FHP, and consequently the calculated NE, from the present experiment are likely more accurate representations of pigs housed under commercial conditions.

The DE and ME of diets were generally in agreement with previous data (Noblet et al. 1994; Rojas and Stein 2013; Lee et al. 2024). The reduction in DE as SBM was replaced by corn indicates that DE is greater in SBM than in corn, which is consistent with previous reports (Rojas and Stein 2013; Sotak-Peper et al. 2015). Likewise, reduced dietary CP resulted in decreased DE, as previously observed (Le Bellego et al. 2001; Cristobal et al. 2025b). Likewise, the decrease in ME as SBM was replaced by corn indicates that SBM may contain more ME than corn. However, this observation differs from previous data that indicated no difference in ME between corn and SBM (Sotak-Peper et al. 2015; Li et al. 2017; Cristobal et al. 2025a) and from literature values that indicate that ME is greater in corn than in SBM (NRC 2012). However, all previous experiments determined ME in individually housed pigs and determining ME in group-housed pigs may influence these estimations. Overall, recent data indicates that DE of SBM may have increased over time, likely due to improvements in processing efficiency and reduced concentrations of anti-nutritional factors (Stein et al. 2024).

The NE values for the diets obtained in this experiment agreed with data from a previous experiment using group-housed pigs (Lee et al. 2024) but were slightly greater than determined in experiments with individually housed pigs (Noblet et al. 1994; Li et al. 2017). The NE obtained in the present experiment was also greater than the NE calculated from the analyzed composition of diets using a published equation (NRC 2012). According to NRC (2012), corn contains more NE than SBM, and if SBM inclusion is reduced while corn inclusion is increased, it is expected that NE of the diet will increase. However, no effects on NE were

Table 5 Standardized ileal digestibility (SID) of crude protein and amino acids (AA),[1,2] experiment 1.

Item	Dietary crude protein							Contrast *P*-value	
	17%	14%	13%	12%	11%	10%	SEM	Linear[3]	Quadratic[3]
Crude protein	85.5	88.7	88.2	91.6	91.0	93.0	1.31	<0.001	0.713
Indispensable AA									
Arg	92.8	93.9	93.3	95.5	95.1	97.0	0.93	<0.001	0.078
His	85.2	87.2	85.6	87.9	88.6	89.5	0.82	0.004	0.249
Ile	84.7	85.2	84.0	87.0	85.5	87.1	0.84	0.041	0.279
Leu	84.7	86.7	86.0	88.2	87.6	88.4	0.79	0.003	0.926
Lys	82.0	85.2	84.6	89.0	88.3	89.3	0.96	<0.001	0.806
Met	87.5	90.2	92.0	91.8	92.7	93.3	0.57	<0.001	0.188
Phe	85.0	86.5	85.6	88.1	87.2	89.2	0.77	0.002	0.243
Thr	78.7	82.4	85.1	87.2	86.3	89.2	1.00	<0.001	0.868
Trp	84.1	89.0	88.7	89.8	91.9	92.9	0.91	<0.001	0.873
Val	83.6	84.7	83.3	86.6	87.2	87.7	0.85	<0.001	0.092
Total	85.0	86.9	86.5	89.1	88.6	89.9	0.76	<0.001	0.452
Dispensable AA									
Ala	82.7	84.6	84.0	87.9	85.9	86.7	1.24	0.008	0.836
Asp	80.0	82.0	81.2	84.6	83.4	84.7	0.93	<0.001	0.743
Cys	76.0	79.6	79.5	81.3	82.3	82.9	1.24	<0.001	0.873
Glu	83.8	87.0	86.9	88.6	88.0	89.1	0.86	<0.001	0.274
Gly	84.4	92.0	91.7	96.8	98.4	103.8	3.35	<0.001	0.339
Pro	115.1	126.1	124.0	139.4	135.9	146.9	11.61	0.005	0.576
Ser	83.0	85.7	85.2	87.7	86.8	88.8	0.99	<0.001	0.766
Tyr	84.6	86.1	85.1	87.8	86.0	87.2	0.76	0.013	0.845
Total	86.2	90.4	89.9	94.1	93.4	96.2	2.00	<0.001	0.658
Total AA	85.5	88.7	88.2	91.6	91.0	93.0	1.31	<0.001	0.713

[1] Each least squares means represents 7 observations.

[2] Values for SID were calculated by correcting values for apparent ileal digestibility for basal ileal endogenous losses. Basal ileal endogenous losses were determined (g/kg of dry matter intake) as crude protein, 10.54; Arg, 0.39; His, 0.13; Ile, 0.28; Leu, 0.40; Lys, 0.29; Met, 0.07; Phe, 0.26; Thr, 0.44; Trp, 0.08; Val, 0.31; Ala, 0.43; Asp, 0.58; Cys, 0.16; Glu, 0.76; Gly, 0.97; Pro, 2.68; Ser, 0.37; Tyr, 0.20; and total AA, 6.10.

[3] Linear or quadratic effects of reducing dietary protein from 17% to 10%.

observed as dietary CP was reduced, indicating that the NE in SBM is close to that in corn. This observation is supported by previous data that indicated no differences in NE between corn and SBM or greater NE in SBM than previously thought (Li et al. 2017; Cemin et al. 2020; Lee et al. 2021; Ibagon et al. 2025). Results from experiment 1 indicate that the lack of differences in NE among diets is not caused by differences in AID of starch or by a decrease in SID of indispensable AA. Therefore, the lack of an effect of dietary CP on NE in diets and the fact that the determined NE in diets was greater than calculated NE indicates that NE in SBM may be underestimated if current prediction equations are used.

This may partly be due to the greater DE in SBM that has been reported (Sotak-Peper et al. 2015). Because NE is calculated from an equation that includes DE, an underestimation of DE will automatically result in an underestimation of NE. The underestimation of NE in SBM may also be partly due to an underestimation of nitrogen retention by modern genotypes of pigs. The equations published by NRC (2012) are based on work conducted more than 30 years ago Noblet et al. (1994). Early studies reported nitrogen retention between 40% and 50% of consumed nitrogen (McConnell et al. 1971; Carr et al. 1977; Campbell and Dunkin 1983), and later experiments reported values between 50 and 60% (Kerr and Easter 1995; Lenis et al. 1999; Le Bellego et al. 2001; Otto et al. 2003; Pedersen et al. 2007; Patrás et al. 2012). However, modern pigs have nitrogen retention greater than 60% when fed diets containing corn and SBM (Rojas and Stein 2013; Li et al. 2017; Corassa et al. 2024; Ochoa et al. 2024; Cristobal et al. 2025a). This improvement in nitrogen retention is likely due to enhanced efficiency in converting dietary protein into body protein, which may be attributed to selective breeding for lean deposition. Increased nitrogen retention indicates that modern pigs are better at utilizing dietary AA for protein synthesis, reducing the need for deamination and urea cycle activity. Because deamination and urea cycle activity are energy-consuming processes, this reduced activity may result in more NE being contributed by the protein fraction of diets when diets are fed to current genotypes of pigs compared with older genotypes. Therefore, both improvements in pig genetics and changes in SBM composition likely contribute to the greater NE values observed in the present experiment and in other recent experiments.

The observation that the NE: DE ratio did not change among diets indicates that the pigs converted the digestible portion of the diet to NE in a similar proportion regardless of dietary CP level. Therefore, the heat increment associated with protein metabolism appears to be comparable to that of the increased starch fraction used to replace protein in the diets with lower CP, resulting in no net change in energy utilization efficiency.

Table 6 Effects of reducing crude protein on apparent total tract digestibility (ATTD) of dry matter, acid-hydrolyzed ether extract (AEE), total dietary fiber (TDF), and gross energy, and concentrations of digestible energy, metabolizable energy, and net energy in diets, and total heat production (THP) and fasting heat production (FHP), as-fed, one pig basis, experiment 2.[1]

Item	Dietary crude protein							Contrast *P*-value	
	17%	14%	13%	12%	11%	10%	SEM	Linear[2]	Quadratic[2]
Feed intake, kg/day	2.8	2.7	2.7	2.8	3.0	2.9	0.19	0.084	0.241
Fecal gross energy output, kcal/day	1,274	1,248	1,275	1,276	1,352	1,313	78	0.144	0.277
ATTD of dry matter, %	88.9	89.1	89.1	89.4	89.2	89.5	0.27	0.066	0.751
ATTD of AEE, %	52.8	47.9	52.4	52.2	51.2	49.4	1.54	0.303	0.746
ATTD of TDF, %	61.0	60.5	56.3	57.0	57.5	55.9	1.47	0.009	0.933
ATTD of gross energy, %	87.9	87.8	87.8	88.0	87.8	87.9	0.32	0.906	0.698
Urine gross energy output, kcal/day	213	182	181	187	174	173	29	0.575	0.714
THP, kcal/$BW^{0.6}$/day	384	375	378	376	390	377	20	0.621	0.704
FHP, kcal/$BW^{0.6}$/day	223	220	235	218	238	221	17	0.878	0.481
Retained energy, kcal/$BW^{0.6}$/day	411	399	406	432	478	433	43	0.100	0.405
Respiratory quotient, fasted state	0.7	0.6	0.6	0.6	0.6	0.7	0.03	0.112	0.217
Respiratory quotient, fed state	1.0	1.0	1.0	1.1	1.1	1.0	0.04	0.199	0.444
Energy in diets, kcal/kg									
Gross energy	3,846	3,802	3,800	3,788	3,785	3,787	-	-	-
Digestible energy	3,380	3,337	3,335	3,333	3,324	3,330	12	0.001	0.075
Metabolizable energy	3,306	3,272	3,269	3,261	3,266	3,271	11	0.008	0.057
Net energy	2,603	2,606	2,663	2,610	2,665	2,634	53	0.333	0.853
Metabolizable energy: digestible energy	1.0	1.0	1.0	1.0	1.0	1.0	0.01	0.058	0.632
Net energy: digestible energy	0.8	0.8	0.8	0.8	0.8	0.8	0.02	0.050	0.538
Net energy: metabolizable energy	0.8	0.8	0.8	0.8	0.8	0.8	0.02	0.065	0.467

[1] Each least squares means represents 6 observations.
[2] Linear or quadratic effects of reducing dietary protein from 17% to 10%.

Table 7 Effects of reducing dietary crude protein on nitrogen balance in group-housed growing pigs (FHP), one-pig basis,[1] experiment 2.

Item	Dietary crude protein							Contrast *P*-value	
	17%	14%	13%	12%	11%	10%	SEM	Linear[2]	Quadratic[2]
Nitrogen intake, g/day	72.4	60.8	52.8	49.9	47.4	40.5	3.67	0.001	0.930
Nitrogen excreted in feces, g/day	9.8	9.4	9.1	9.1	9.2	8.5	0.49	0.005	0.730
Nitrogen excreted in urine, g/day	18.8	11.9	9.6	8.2	6.1	6.4	2.40	0.001	0.079
Absorbed nitrogen, g/day	62.6	51.4	43.7	40.8	38.3	32.1	3.33	0.001	0.370
Retained nitrogen, g/day	43.9	39.5	34.1	32.6	32.2	25.8	2.04	0.001	0.230
ATTD[3] of nitrogen, %	86.3	84.4	82.8	81.5	80.5	78.8	0.76	0.001	0.011
Nitrogen retention, % of intake	61.3	65.6	65.5	66.0	67.8	64.6	3.00	0.031	0.106
Biological value of crude protein, %[4]	71.1	77.9	79.1	81.1	84.3	82.1	4.01	0.001	0.281

[1] Each least squares means represents 6 observations.
[2] Linear or quadratic effects of reducing dietary protein from 17% to 10%.
[3] ATTD = apparent total tract digestibility.
[4] Calculated according to Rojas and Stein 2013.

The ATTD of N, absorbed and retained nitrogen calculated as g per day, and nitrogen retention calculated as percent of intake agreed with previous data (Rojas and Stein 2013; Li et al. 2017; Lee et al. 2024; Cristobal et al. 2025a). Results indicate that there is a relationship between reducing dietary CP and changes in nitrogen balance in growing pigs. As expected, nitrogen intake decreased as dietary CP was reduced, with pigs fed the diet with 10% CP consuming significantly less nitrogen than those fed 17% CP, which is consistent with previous data (Kerr and Easter 1995). The reduction in nitrogen excretion as dietary CP was reduced is likely due to the improved efficiency of nitrogen utilization in pigs fed lower protein diets, as previously indicated by others (Wang et al. 2018). In contrast, the reduction in fecal nitrogen was smaller than the reduction in urinary nitrogen, indicating that the changes in nitrogen excretion were mainly influenced by reduced urinary losses rather than fecal losses, which was expected because fecal losses of nitrogen are only influenced by nitrogen intake and ATTD of nitrogen. Although the ATTD of nitrogen was reduced as diet CP was reduced due to the lower ATTD of nitrogen in corn than in SBM, the effect of reduced intake was greater than the effect of reduced ATTD of nitrogen, which likely explains the reduced total excretion of nitrogen that was observed as diet CP was reduced.

The observation that absorbed nitrogen and retained nitrogen (g/d) decreased with lower CP diets is consistent with reported data (Kerr and Easter 1995; Cristobal et al. 2025a). This indicates that post-absorptive AA metabolism is less efficient when pigs are fed diets containing corn and synthetic AA compared with corn and only SBM. Reduced daily nitrogen retention indicates that overall, less protein synthesis may occur when SBM is reduced and more synthetic AA are added to diets for growing pigs. It is therefore likely that pigs fed diets with reduced CP have reduced protein deposition and, therefore, reduced lean meat percentage, which has been previously reported (Smith et al. 1999; Li et al. 2016; Wang et al. 2017).

Conclusions

The hypothesis that reducing dietary CP by reducing dietary SBM and increasing corn and synthetic AA would not affect AID of starch or NE of diets was confirmed. However, the hypothesis that reducing dietary CP and supplementing with synthetic AA would not affect SID of CP and AA was rejected as a linear increase was observed for SID of CP and for indispensable and dispensable AA. Overall, these results indicate that from an energetic point of view there is no advantage of reducing dietary SBM concentrations, but the observation that the NEof SBM likely is greater than current book values may imply a need for reevaluation of published nutrient tables.

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Author contributions

Hans H. Stein (Conceptualization, Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing—review & editing), Minoy Cristobal (Data curation, Formal analysis, Investigation, Methodology, Writing—original draft), Su A. Lee (Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing—review & editing), and Carl M. Parsons (Investigation, Project administration, Supervision, Writing—review & editing)

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Data availability

All data from the experiments are included in the manuscript.

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