

NPB FINAL RESEARCH GRANT REPORT FORMAT

As a requirement of each research grant, a final report detailing the project results must be provided to the National Pork Board. Please write the industry summary with the producer in mind. The remaining content of the report can be written for a scientific audience. ALL final reports must be submitted in the following format or the report will be returned for correction. PLEASE DO NOT INCLUDE ANY TYPE OF COVER PAGE.

Project Title and NPB project identification number

Improving feed efficiency of growing to finishing pigs fed high DDGS containing diet with different branched-chain amino acids to lysine ratio (NPB #21-103)

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Industry Summary: Corn distillers dried grains with solubles (cDDGS) can replace portions of corn and soybean meal (SBM) in swine diets. However, high dietary inclusions of cDDGS can reduce growth performance, which is most likely related to high dietary concentrations of one of the branched-chain amino acids (BCAA), leucine (Leu). The objective of this study was to identify the effects of feeding diets with cDDGS inclusions of 30% (grower) and 20% (finisher) with different ratios of BCAA to lysine (Lys) on the growth performance, blood amino acid profile, carcass traits, and economics of growing-finishing pigs. A total of 1,140 pigs with an average starting body weight of 63 lbs were housed in a tunnel ventilated barn containing 45 pens with 25 or 26 pigs per pen. Pigs were fed one of five dietary treatments over four dietary phases until marketed. Diets consisted of a corn-SBM diet, a corn-SBM-cDDGS diet without BCAA to Lys adjustments, or one of three corn-SBM-cDDGS with BCAA to Lys adjustments from SBM for growing (Grow), finishing (Finish), or growing and then finishing (Grow-Finish) recommendations. After 11-weeks, pigs were marketed through a commercial abattoir to collect carcass traits. Pigs fed diets with the BCAA to Lys ratio adjusted for finishing pigs by SBM had a greater overall average daily gain ($P < 0.05$) than pigs fed the other cDDGS diets. The dietary treatments did not affect the hot carcass weight or carcass yield. However, the same diet that improved growth performance resulted in greater ($P < 0.05$) iodine value of the pork belly. One pig from each pen was bled at the end of the growing and finishing phases. The blood concentration of nitrogen from amino acid breakdown at the end of growing phase and the blood amino acid concentration of Leu and Val were greater ($P < 0.05$) in pigs fed the Finish diet. Feeding the cDDGS diets with different BCAA:Lys ratios had no difference in income over feed cost and income over feed and facility costs compared to the corn-SBM diets. In conclusion, feeding 30% (grower) and 20% (finisher) cDDGS diets with the BCAA to Lys ratio for the finishing phase recommendation adjusted by SBM inclusion will benefit swine producers by improving growth performance and providing economic benefits equal to the corn-SBM diet.

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Key Findings:

- Feeding cDDGS diets with the BCAA to Lys ratio adjusted by SBM inclusion:
 - improved growth performance
 - Similar net income compared to corn-SBM diet
 - increased the iodine value of the pork belly

Keywords: corn distillers dried grains with solubles, branched-chain amino acids, growth performance, blood profile, carcass traits, economic performance, growing-finishing pigs

Scientific Abstract: A study was conducted to identify the effect of standardized ileal digestible (SID) branched-chain amino acids (BCAA) to lysine (Lys) ratios on the growth performance, blood amino acid profile, carcass traits, and economic analysis in growing-finishing pigs fed diets with high corn distillers dried grains with solubles (cDDGS) inclusions. A total of 1,140 pigs (initial body weight [BW] = 28.7±0.7 kg) were housed in 45 pens of 25 or 26 pigs and fed 1 of 5 experimental treatments in a randomized complete block design. Experimental treatment diets were fed in 4 phases (2 grower and 2 finisher) based on BW. There were a total of 5 dietary treatments: 1) a corn-SBM based diet (PC); 2) a corn-SBM based diet with 30% cDDGS for growing phase and 20% DDGS for finishing phase (NC) with no adjustments for BCAA:Lys and the NC diet with SID BCAA:Lys targeted for our previously determined recommendations for the 3) growing phase (Grow); 4) finishing phase (Finish); 5) growing and finishing phases (Grow-Finish). One pig from each pen was bled at the end of the growing and finishing phases. After the 11-week-feeding trial, pigs were sent to a commercial abattoir to investigate carcass traits. Pigs fed the Finish treatment had a greater overall average daily gain ($P < 0.05$) compared to pigs fed the other cDDGS treatments. Dietary treatments did not affect the hot carcass weight or carcass yield. However, feeding the Finish treatment caused the greatest ($P < 0.05$) iodine value of the pork belly. The plasma urea nitrogen concentration at the end of growing phase and the plasma concentrations of Leu and Val were greater ($P < 0.05$) in pigs fed the Finish dietary treatment. Feeding pigs the cDDGS diets with different BCAA:Lys ratios had no difference in income over feed cost and income over feed and facility costs compared to the corn-SBM diet. Therefore, feeding the cDDGS diet with SID BCAA:Lys ratio adjusted by the SBM inclusion for the finishing phase recommendation would have the greatest benefit for swine producers in terms of the improved growth performance and economic benefits equal to the corn-SBM diet.

Introduction: Corn distillers dried grains with solubles (cDDGS) is used primarily as an alternative ingredient in swine diets replacing a portion of the corn and soybean meal (SBM) to reduce cost of the diets. Previous studies have reported that reduced oil (< 10%) cDDGS can be included up to 30% of the swine diets without detrimental effects on growth performance when adequate energy and digestible amino acids values for cDDGS were used in the diet formulations (Kerr et al., 2015). However, increasing the dietary inclusion of cDDGS can lead to high concentrations of leucine (Leu) in swine diets. For example, if a corn-SBM based diet with 30% cDDGS is fed to growing pigs, dietary Leu will be 150% to 200% of the requirement according to NRC (2012). According to a meta-analysis (Cemin et al., 2019), high cDDGS diets with excess Leu negatively affects average daily gain (ADG) and average daily feed intake (ADFI) of pigs and reduces gain to feed ratio (G:F) caused by insufficient levels of other branched-chain amino acids (BCAA)

and large neutral amino acids (LNAA) relative to Leu in the diets. A high cDDGS diet providing excess Leu may result in amino acid (AA) imbalance, reduced nitrogen retention and growth performance of pigs (Morales et al., 2016; Kwon et al., 2019). Since BCAA (Leu, valine (Val), isoleucine (Ile)) are structurally similar and share the first two steps of their catabolic pathway (Harris et al., 2005), excess Leu may decrease the availability of Val and Ile for protein synthesis and cause reductions in protein retention (Wiltafsky et al., 2010) Furthermore, tryptophan (Trp), a precursor of serotonin and involved in feed intake regulation, and Leu are both categorized as LNAA. They share a common uptake pathway across the blood-brain barrier (Barea et al., 2009) thus, excess Leu may have an inhibitory effect on feed intake of pigs by reducing Trp uptake into the brain due to competition for AA transporters (Wessels et al., 2016a).

Recent studies have been conducted to ameliorate the poor performance of pigs fed diets containing high Leu concentrations from high cDDGS inclusions through additions of Val, Ile, or Trp in the diet formulations. Kwon et al. (2020) reported that Val supplementation (60% to 80% Val:lysine (Lys) ratio) to diets with excess Leu increased the efficiency of AA utilization for protein synthesis in growing pigs as evidenced by reduced plasma urea nitrogen (PUN) concentrations. Kerkaert et al. (2021) reported that increasing the ratios of Val and Ile relative to Lys (lysine) can reverse the negative effects of high Leu concentrations in 30% cDDGS diets on growth performance of growing and finishing pigs. In the study of Kerkaert et al. (2021), a high Val:Lys ratio (76-80%) showed a greater ADG of pigs for the growing period, whereas a high Ile:Lys ratio (66-68%) showed greater ADG and G:F of pigs for the finishing period. Clizer et al. (2022a) found that a Val:Lys ratio of 73% would provide maximum G:F during the growing period when pigs were fed the diet containing cDDGS at 30%. Also, Clizer et al. (2022b) determined that a Ile:Lys ratio of 70% appeared to achieve maximum growth performance of finishing pigs when they were fed the diet containing 20% cDDGS. Regarding the meta-regression analysis to predict the influence of BCAA and LNAA on growth performance of pigs (Cemin et al., 2019), the results of Kerkaert et al. (2021) and Clizer et al. (2022a,b) indicated that there is a nutrition gap between the estimated requirements and real requirements of BCAA in the diet with inclusions of cDDGS over 20% for growing to finishing pigs. Taken together, it should be noted that the alleviating effects of Val or Ile supplementation in high cDDGS diets showed different concentrations in the growing versus the finishing period, respectively. Unlike most amino acids, the BCAA increase rapidly in systemic circulation after protein intake and initial catabolism of the BCAA takes place in the skeletal muscle due to the high activity of BCAA aminotransferase (Holeček, 2018). Also, dietary BCAA are involved in the muscle protein synthesis (Yoon, 2016; Kwon et al., 2019). In pigs, lean tissue deposition increases as pigs advance in body weight (BW) up to 64 kg before protein deposition rate decreases and fat deposition increases as pigs age (National Swine Nutrition Guide, 2010); protein deposition (muscle synthesis) occurs favorably in the growing period and fat deposition occurs more in the finishing period. Application of a single ratio of BCAA:Lys in high cDDGS diets for the overall growing-finishing period may cause AA imbalance, increasing feeds cost due to the expense of synthetic BCAA and increased nitrogen excretion in manure. Therefore, the optimal ratio of BCAA to Lys in high cDDGS diets with high concentrations of Leu for grow-finish pigs should be determined and, if necessary, applied differently for growing and finishing pig diets.

Objectives: To alleviate the negative effects of high cDDGS inclusions, the optimal ratio of standardized ileal digestible (SID) BCAA to Lys in the high cDDGS diets for pigs should

be assessed and there is a need to investigate the implementation of BCAA:Lys ratios for pigs within growth phase. Thus, the objective of the research project was to identify the effects of BCAA:Lys ratios on the performance response of growing and finishing pigs fed diets with high inclusions of cDDGS (30% during the growing period and 20% during the finishing period) to determine the best implementation strategy for high cDDGS diets balanced with BCAA:Lys ratio. In addition, this research project would reduce the knowledge gap between the predicted regression models and the actual pig performance of pigs fed the high cDDGS diets providing high Leu contribution to the diets. Through this research project, we aimed to provide scientific and reliable information regarding cost-effective use of high levels of cDDGS in swine diets to improve feed efficiency of pigs.

Objective 1. Evaluate the effects of SID BCAA:Lys ratio on performance response of growing and finishing pigs fed the diets containing high levels of DDGS (30% & 20%, respectively). The working hypothesis is that application of different SID BCAA:Lys ratios for the growing period and finishing periods will improve the growth performance and carcass characteristics of pigs fed the diets with high inclusions of cDDGS.

Objective 2. Investigate the effects of high cDDGS diets balanced with SID BCAA:Lys ratio on nitrogen balance of pigs during growing and finishing periods. The working hypothesis is that adequate ratio of SID BCAA:Lys for each feeding phase will improve the nitrogen utilization and nitrogen retention, resulting in a decrease of nitrogen excretion.

Objective 3. Examine whether high cDDGS diets with balanced SID BCAA:Lys ratio throughout the growing and finishing period will reduce feed and production costs for swine producers. The working hypothesis is that adequate ratio of SID BCAA:Lys for each feeding phase will improve the feed efficiency for growing and finishing pigs, which results in a reduction of feed cost and swine production cost during the growing and finishing period with high inclusion levels of cDDGS in swine diets.

Materials & Methods:

The experimental procedures were reviewed and approved by the Institutional Animal Care and Use Committee at South Dakota State University (#2107-040E).

Experimental Animals

A total of 1,140 growing pigs (initial body weight [BW] of 28.7±0.7 kg; DNA 610 × PIC) were used in a grow-finish feeding trial at South Dakota State University commercial wean to finish research facility (Flandreau, SD, USA). The pigs were allotted to 45 pens of 25 or 26 pigs/pen balanced for BW and sex. Pens (3.1 × 6.9 m) had fully slatted-concrete floors, metal spindle walls (1.0 m high), and solid polyvinyl chloride gates. Each pen was equipped with two cup waterers, and a five-slot dry feeder (SD Industries, Alexandria, SD). Room temperature setpoints were 20.5, 18.3, 16.7, and 16.1 °C for d 1, 28, 56, and 77, respectively, throughout the experiment.

Experimental Diets

Experimental diets were fed in 4 phases based on BW: Phase 1: 25-50 kg, Phase 2: 50-75 kg, Phase 3: 75-100 kg, and Phase 4: 100-135 kg. Five experimental diets were based on corn, SBM, and cDDGS in this study. The diets contained 30% cDDGS for growing phases (Phase 1 and 2) and 20% cDDGS for finishing phases (Phase 3 and 4).

Dietary treatments (Table 1) consisted of: 1) Positive control (PC): a corn-SBM based diet with SID BCAA:Lys of PIC (2020) for the overall experimental period, 2) Negative control (NC): a cDDGS diet with SID BCAA:Lys of PIC (2020) for the overall experimental period; 3) a cDDGS diet with SID BCAA:Lys targeted for the growing phase for the overall

experimental period; 4) a cDDGS diet with SID BCAA:Lys targeted for the finishing phase for the overall experimental period; 5) a cDDGS diet with SID BCAA:Lys targeted for the growing phase for phases 1 and 2 and SID BCAA:Lys targeted for the finishing phase for phases 3 and 4. Based on the results of our previous studies (Clizer et al., 2022a,b), the SID Val:Lys ratio of 73%, SID Ile:Lys ratio of 60%, and SID Leu:Lys ratio of 144% were provided for the growing period and the SID Val:Lys ratio of 78%, SID Ile:Lys ratio of 70%, and SID Leu:Lys ratio of 160-170% were provided for the finishing period (Table 1). The SID lysine was formulated to 95% of the requirement for maximum protein deposition of the given weight bracket to ensure responses in growth performance are due to changes in AA concentrations. The SID BCAA:Lys ratios in the diets were adjusted by the SBM inclusion level without using synthetic BCAA. The diets were formulated to meet the nutrient requirement of pigs according to the PIC Nutrition and Feeding guideline (2020).

Experimental Design and Procedure

The 5 diets were allotted to the 45 pens (9 pens/diet) within a randomized complete block design. The diets were fed in 4 phases based on BW; Phase 1: 25-50 kg, Phase 2: 50-75 kg, Phase 3: 75-100 kg, and Phase 4: 100-135 kg. During the experimental period, diets and fresh water were offered to pigs ad libitum. Pen weights and feed disappearance were measured on the end of each phase to calculate average daily gain (ADG), average daily feed intake (ADFI), and gain-to-feed ratio (G:F). At the end of 7 weeks and 13 weeks, one pig of average BW from each pen was selected and bled from the jugular vein of the selected pigs using vacutainer tubes (BD Vacutainer®, K₂E EDTA, Plymouth, UK).

After the end of phase 4 (11 weeks), groups of pigs balanced with similar numbers of pigs from each pen were sent to a commercial abattoir to investigate hot carcass weight and carcass yield for 4 weeks; first cut (11 weeks): 171 pigs, second cut (12 weeks): 334 pigs, third cut (13 weeks): 335 pigs, and fourth cut (14 weeks): 266 pigs. Prior to shipment to the processing facility, groups for pigs selected for market within pens were weighed via pen scale. Carcass yield was calculated using hot carcass weight at the plant divided by live weight at the barn on a pen basis. In second and third loadings, four gilts from each pen were selected for measuring the iodine value (IV) of pork belly (n = 36/treatment) at the processing facility (Wholstone Farms, Fremont, NE).

For economic evaluation, feed costs for each feeding phase were calculated based on the sale price of the ingredients on December, 2021. Prices used for corn, SBM, and cDDGS were \$0.22, \$0.36, and \$0.18/kg, respectively. Economic comparisons were made based on a constant ending weight at 127 kg (280 lb). The ADG and ADFI for 10 to 11 weeks were used to calculate the estimated additional feeding days and feed consumptions reaching to the ending weight. Total feed cost was calculated by multiplying pig feed intake for each phase by feed cost for each phase. Carcass price at time of slaughter was calculated at \$1 per pound according to the USDA report from March, 2022.

Cost per kilogram of carcass gain was calculated by dividing the total feed cost per pig by the total hot carcass weight gain. Carcass gain value was calculated by multiplying total carcass gain weight by carcass price. Total feed cost was calculated by multiplying feed consumption for each phase by feed cost for each phase: feed consumption for Phase 4 was calculated from 10 weeks to 14 weeks (last market pigs loading). Income over feed cost (IOFC) was calculated by subtracting the total feed cost from the carcass gain value. The income over feed and facility cost (IOFFC) was calculated by subtracting a facility cost from the IOFC. The facility cost was calculated by multiplying the feeding days by \$0.1 per head per day facility cost.

Sample Preparation and Analyses

Diet and ingredient (corn, SBM, and cDDGS) samples were ground through a 0.75-mm screen in a centrifugal mill (model ZM200; Retsch GmbH, Haan, Germany). The ground samples were analyzed for moisture by oven drying at 135°C for 2 hours (method 930.15), crude ash by using muffle furnace at 600°C for 10 hours (method 942.05), crude protein (CP) by a combustion analysis (method 990.03), ether extract (EE) by an Soxhelt extraction (method 920.39), crude fiber by Weende method (method 978.10) as per AOAC (2007), and for acid detergent fiber (ADF) and neutral detergent fiber (NDF) by van Soest method (model 3000, Labconco, Kansas city, MO, USA). The complete amino acid profile was analyzed by the AOAC method (2007; 982.30).

The collected blood samples were centrifuged at 1,872 x g for 20 min at 4 °C and the sera of the centrifuged plasma samples were stored at -20 °C until further analysis. The concentration of plasma urea nitrogen (PUN) was measured by colorimetric assay (Urea nitrogen colorimetric detection kit, Invitrogen, Carlsbad, CA).

Plasma samples were filtered by 10K centrifugal filter (Modified PES 10K VWR Centrifugal Filter, VWR North America, Radnor, PA). The filtered plasma samples were analyzed for amino acids profile by high-performance liquid chromatography (HPLC). The pork belly samples were cut from the carcass and subjected to the analysis of iodine value by using FT-NIR spectrophotometer (Fourier transform near-infrared spectrophotometry Tango, Bruker, Billerica, MA). The selected samples were cut and blended, placed on a glass petri dish located directly above the quartz window of the integrating sphere spectrometer. Samples were scanned across the NIR spectral range (12,500 to 4,000 cm⁻¹) with a resolution of 8 cm⁻¹ and were measured 5 times at different sampling points and an average spectrum value was taken to calculate the iodine value.

Statistical Analysis

Data were subjected to analysis of variance using the GLIMMIX procedure (SAS Inst. Inc., Cary, NC, USA). The pen was considered as the experimental unit. To test the hypotheses, $P < 0.05$ was considered significant. If pertinent, trends ($0.05 \leq P < 0.10$) are also reported.

Results:

Ingredients and Diets Analysis

The analyzed nutrient composition of ingredients, including corn, SBM, and cDDGS that were used in the current study (Table 2). The cDDGS contained 30% crude protein, 6.6% crude fat, 31% NDF, and 13% ADF.

The SID Val, Ile, and Leu to Lys ratios in cDDGS diet targeted for the requirement of growing phase were close to the referenced values and the SID Val, Ile, and Leu to Lys ratios in cDDGS diet targeted for the requirement of finishing phase were in the range of reference values (Table 1). Since the SID BCAA:Lys ratios in the cDDGS diets were adjusted by the SBM inclusion rate, there are limitations of formulating the diets containing identical SID BCAA:Lys ratio.

Growth Performance

Meeting the previously determined recommendations of SID BCAA:Lys for the finishing phase tended to improve ($P = 0.06$) the BW of the pigs fed the cDDGS diets at the end of Phase 4 which were similar to the BW of pigs fed a corn-SBM based diet (PC diet) without DDGS inclusion (Table 4). Pigs fed a PC diet had a greater ($P < 0.05$) ADG for phase 2 than that of pigs fed the cDDGS diet (NC diet). Pigs fed the cDDGS diet with SID

BCAA:Lys for the finishing phase requirement (Finish diet) had greater ($P < 0.05$) ADG for phase 2 than that of pigs fed the NC diet and for phase 3 than that of pigs fed the cDDGS diet with SID BCAA:Lys for growing phase and growing-finishing phases (Grow and Grow-Finish diets). During the overall period, pigs fed the Finish diet had a greater ADG ($P < 0.05$) than pigs fed the other cDDGS diets and had no difference in the overall ADG compared to pigs fed the PC diet. The ADFI for phase 3 was decreased ($P < 0.01$) in the pigs fed the Grow-Finish diet compared to all other treatments. In comparison with PC treatment for G:F, cDDGS diets without or with adjusting the SID BCAA:Lys ratio did not affect the G:F for Phase 1, 2, and 3 and overall period. However, pigs fed the Grow or Grow-Finish diets showed a tendency of decreased ($P = 0.06$) in G:F for Phase 4 compared to those of pigs fed the PC diet.

Carcass traits

Dietary treatments did not impact ($P > 0.14$) hot carcass weight or carcass yield (Table 5). The iodine value of pork belly samples from the pigs fed cDDGS diets was greater ($P < 0.01$) than that of pigs fed a corn-SBM diet without DDGS inclusion. However, pigs fed the Finish diets had a greater ($P < 0.01$) iodine value of pork belly samples than the pigs fed other cDDGS diets.

Blood profile

The concentration of PUN for at the end of phase 2 in pigs fed the cDDGS diet with SID BCAA:Lys for the finishing phase was greater ($P < 0.01$) than other dietary treatments (Table 6). However, different SID BCAA:Lys ratio in cDDGS diets did not affect the PUN concentration for phase 4 ($P = 0.62$).

At the end of Phase 2, the plasma concentrations of Leu were higher ($P < 0.01$) in the pigs fed cDDGS diets compared to that of pigs fed a corn-SBM diet (Table 7). Pigs fed the Finish diet had greater ($P < 0.05$) plasma concentrations of Ile, Val, and Phe than pigs fed other cDDGS diets. The plasma concentrations of Thr in pigs fed the cDDGS diets with the SID BCAA:Lys adjusted SBM inclusion were less ($P < 0.02$) than that of pigs fed the PC diet. Pigs fed the Finish diet showed a greater ($P < 0.01$) plasma concentration of His and a tendency of an increase ($P = 0.05$) in plasma concentration of Arg than pigs fed the NC diet. On the other hand, pigs fed the Finish diets showed a lower ($P < 0.01$) plasma concentration of Gly than pigs fed other diets and showed a lower ($P < 0.01$) plasma concentration of Glu than pigs fed NC diet.

At the end of 13 weeks during the Phase 4 feeding, the plasma concentrations of Leu were higher ($P < 0.01$) in the pigs fed cDDGS diets compared to pigs fed a corn-SBM diet (Table 8). The plasma concentrations of Ile and Val in pigs fed the Finish diet were greater ($P < 0.02$) than pigs fed the NC and Grow diets. Pigs fed the Grow-Finish diets showed a lower ($P < 0.03$) plasma concentration of Lys and a tendency of a decrease ($P = 0.07$) in plasma Thr concentration compared to the pigs fed the PC and NC diets, whereas pigs fed the Grow diet had a greater ($P < 0.05$) concentration of plasma Met than the pigs fed the NC diet. Pigs fed the Finish or Grow-Finish diets showed a greater ($P < 0.01$) concentration of plasma Arg than pigs fed the NC diet. Pigs fed the cDDGS diets showed greater ($P < 0.04$) concentrations of plasma His and Pro than pigs fed the PC diet.

Economic analysis

The cDDGS diets with adjusted SID BCAA:Lys by SBM inclusion had lower feed cost per ton for phases 1 to 4 by 4.7%, 4.6-5.2%, 3.0-3.3%, and 2.2-3.2% compared to the corn-SBM diet (Table 9). Considering production economics, feeding the Finish diet had no difference in IOFC and IOFFC compared to feeding the PC and NC diets.

Discussion:

The final BW and overall ADG of pigs fed the cDDGS diets with the Clizer et al. (2022b) recommendations of SID BCAA:Lys for finishing phase were greater than those of pigs fed the other DDGS diets and similar to those of pigs fed the corn-SBM based diet. High levels of Leu in the cDDGS-containing diets have been shown to negatively affect the growth performance of growing-finishing pigs due to an imbalance in BCAA and LNAA relative to Leu (Cemin et al., 2019; Kwon et al., 2019; Kerkaert et al., 2021). In the current study, the SID BCAA:Lys ratios in the cDDGS diets were adjusted by the SBM inclusion level without using synthetic BCAA in consideration of the observations of Clizer et al. (2021) and Anderson (2021) which both suggested that dietary SBM inclusion improved pig growth performance compared to cDDGS diets with synthetic AA. In the study of Kerkaert et al. (2021) and the current study, the increased levels of SBM in the cDDGS diets increased the dietary level of Val, Ile, and/or Trp. Thus, the greater growth performance of pigs fed the cDDGS diet with the recommended SID BCAA:Lys for the finishing phase could partly have been due to the higher inclusion of SBM and, therefore, higher dietary intakes of Val and Ile.

During the Phase 3 feeding, pigs fed the Grow and Grow-Finish diets showed lower ADG than pigs fed the Finish diet. The Finish diet for Phase 3 was formulated to meet the requirement of BCAA for the finishing phase and the Grow diet for Phase 3 was formulated to meet the requirement of BCAA for the growing phase, which resulted in the difference in the dietary level of BCAA during the finishing phase. Thus, the lower ADG of pigs fed the Grow diet could partly have been attributed to the imbalance in the dietary BCAA. However, the ADG of pigs fed the Grow-Finish diet was lower than that of pigs fed the same diet (Finish diet). In general, the growth of pigs is positively related to voluntary feed intake or nutrient intake. The decreased ADFI in pigs fed the Grow-Finish diet for Phase 3 observed in the current study resulted in the decreased ADG of the pigs. Kwon et al. (2019) observed that increasing dietary Leu decreased plasma Trp concentration and decreased serotonin concentration in plasma and the hypothalamus. Dietary Trp is a substrate for the synthesis of serotonin in the brain, which plays a critical role in appetite regulation (Shen et al., 2012; Höglund et al., 2019). The LNAA, including Trp, share the same brain transporters with BCAA across the blood-brain barrier (Barea et al., 2009), which implies that high intake of dietary BCAA could have been negatively correlated with Trp uptake and serotonin synthesis in the brain (Wessels et al., 2016a, 2016b). Low intake of dietary Trp reduced voluntary feed intake of pigs due to the decreased serotonin synthesis in the hypothalamus (Henry et al., 1992; Wessels et al., 2016b). Thus, the lower ADFI and ADG of pigs fed the Grow-Finish diet could partly have been explained by the dramatic increase in dietary BCAA levels from Phase 2 to Phase 3 such as SID Val:Lys, SID Ile:Lys and SID Leu:Lys by 9%, 9%, and 22%, respectively. The increase in dietary BCAA levels for Grow diet from Phase 2 to Phase 3 were 1% for SID Val:Lys, 0% for SID Ile:Lys, and 15% for SID Leu:Lys.

The iodine value of carcass has been considered as an index of pork fat quality. Packers have recommended maximum acceptance of carcass fat IV ranging from 70 to 75% (Benz et al., 2011). The IVs of belly fat from the pigs fed cDDGS diets in the current study were similar to the IV of backfat from the pigs fed the diet with 30% cDDGS reported by Cromwell et al. (2011). However, in the current study, the IV of pigs fed the cDDGS diets with the requirement of SID BCAA:Lys for the finishing phase were greater than those of other pigs fed the cDDGS diets and reached 80%. McClelland et al. (2012) reported that high IV of belly fat at 79.5% by feeding cDDGS did not negatively affect the

slicing yield of cured bellies, quality of fresh bacon slices, or eating quality of bacon, sausage, or loin chops. Thus, IV ranging from 77 to 80% would be in the feasible range of pork quality for packers and customers. Although, further research is warranted to reduce IV to within the commonly accepted range.

The concentration of PUN in pigs has been considered as an index blood marker for determining the protein requirement of pigs because excessive intakes of amino acids are inefficiently metabolized and circulated in the blood before urinary excretion (Whang and Easter, 2000; Hong et al., 2016). The greater concentration of PUN in pigs fed the Finish diet at the end of the growing phase could partly have been due to the excessive intakes of BCAA. Kwon et al. (2019) reported that pigs fed a 300% SID Leu:Lys diet showed greater PUN concentration than pigs fed a 100% SID Leu:Lys diet. They also observed that increasing SID Val:Lys ratio in the diet from 60% to 80% decreased the PUN concentration in growing pigs, which implied that the optimal requirement of Val in growing pigs is close to the 70 - 80% of SID Val:Lys in agreement with the observation of Clizer et al. (2022a) of 73% SID Val:Lys for growing pigs and 78% SID Val:Lys for finishing pigs of Cemin et al. (2019).

Greater plasma concentrations of Val and Ile in pigs fed the Finish diet were observed in the current study, which could be explained by the higher dietary intake of BCAA than other diets. Kwon et al. (2019) reported that increasing dietary SID Leu from 100% to 300% relative to the requirement increased the plasma Leu concentration linearly. In the other LNAA, plasma concentrations for Trp were not affected by the different levels of SID BCAA:Lys in the cDDGS diet, which was in agreement with the observation of Kwon et al. (2019). However, plasma concentrations for Tyr and Phe were increased at the end of the growing phase when the pigs were fed the cDDGS diet with the BCAA requirement for the finishing phase. Since the BCAA and other LNAA including Ile, Leu, Val, Phe, Trp, and Tyr share the same brain transporters (Henry et al., 1992; Fernstrom, 2005), excess intake of dietary BCAA cause the inefficient utilization of the dietary LNAA and then the excess LNAA, after body utilization, are circulated in the blood. Thus, the increased level of plasma Phe and Tyr at the end of the growing phase could partly have been due to the higher intake of BCAA in the cDDGS diet targeting for the SID BCAA:Lys requirement of finishing pigs. However, additional research is required to determine if the other BCAA including Ile and Val change the plasma LNAA concentrations.

In the current study, plasma concentrations of Thr were decreased in pigs fed the cDDGS diets. High fiber content in cDDGS results in increased endogenous losses of digestive enzymes, enterocytes, and mucin (Dilger et al., 2004; Urriola et al., 2010). Threonine is a major component for mucin secretion (Montagne et al., 2003) and increased mucin production and reduced body Thr retention (Schaart et al., 2005; Munasinghe et al., 2017). Thus, the decreased level of plasma Thr could partly have been due to the higher mucosal secretion and increased SID Thr:Lys requirement by the dietary high fiber intake from the cDDGS diets.

The changes in the plasma concentrations of Pro, Arg, Gln, and Gly were affected by their concentrations in the cDDGS and the diets. The cDDGS used in the current study contained half of Arg, Glu, Gly, and similar Pro contents compared to SBM. In the current study, the SID BCAA:Lys ratios in the cDDGS diets were adjusted by the SBM inclusion level without using synthetic BCAA. Thus, the changes in the plasma concentrations of Pro, Arg, Gln, and Gly were followed by the trend of the diet AA contents adjusted by the SBM and 30% cDDGS.

Interestingly, the plasma Lys concentration at the end of 13 weeks was decreased in the pigs fed the cDDGS diet with the SID BCAA:Lys requirement for the finishing phase. Lysine-Arg antagonism is a well-established AA interaction because Lys and Arg share some common chemical properties (Ball et al., 2007). If excess dietary Arg increased the requirement for Lys in pigs, a decreased blood concentration of Lys would result (Hagemeier, 1982). However, additional research is needed to investigate if the changes in blood Lys and Arg are determined by the Lys-Arg antagonistic effect from the cDDGS diet or the other factors.

Because of the lower cost of cDDGS compared to corn and SBM feedstuffs, the costs for the cDDGS diets were lower than the corn-SBM diet. Although the growth rate of pigs fed the Finish diet was greater than other cDDGS diets, the Finish diet showed the lowest IOFC and IOFFC in comparison due to relatively lower carcass gain value and higher total feed cost. Nemechek et al. (2015) reported that pigs fed diets with cDDGS had poorer growth performance, decreased hot carcass weight, reduced carcass yield, and higher carcass fat IV than pigs fed the corn-SBM diet. However, in the current study, pigs fed the cDDGS diets had no difference in carcass weight, but did have increased IV of the pork belly and decreased carcass yield. Considering the net income for pigs fed the Finish diet compared to the corn-SBM-based diet and other cDDGS diets within this project, the feeding strategy did not deliver an economic benefit.

In conclusion, the inclusion of cDDGS in the growing-finishing pig diets with the SID BCAA:Lys requirement for the finishing phase adjusted by SBM inclusion improved the growth performance of the pigs, resulted in equal economic benefits compared to the corn-SBM diet. However, it resulted in a greater PUN concentration at the end of the growing phase and a greater IV of the carcass. Regarding the growth and economic performances, feeding the cDDGS diet with the requirement of SID BCAA:Lys for the finishing phase would have a higher economic benefit than feeding the corn-SBM diet for swine producers.

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Any publications, presentations or abstracts of the project results, need to recognize proper funding credit. A statement such as this would be sufficient: "Funding, wholly or in part, was provided by the National Pork Checkoff" (Or in the case of state funding "on behalf of the [state] Pork Producers Association"). Thank you for your attention to these instructions. Please contact Bev Everitt (phone-515/223-2750 or E-mail: beveritt@pork.org if you have any questions.

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Table 1. Standardized ileal digestible BCAA:Lys ratio in the experimental diets

Item	Target ratio	Calculated SID BCAA:Lys ratio adjusted by SBM				
		PC ¹	NC	Grow	Finish	Grow-Finish
Growing phase, (Phase 1, Phase 2)						
SID Val:Lys, %	68	68	68	73	78, 81	73
SID Ile:Lys, %	60	64, 62	59, 56	64, 61	70	64, 61
SID Leu:Lys, %	140-150	120	136	143	150	143
Finishing phase, (Phase 3, Phase 4)						
SID Val:Lys, %	78	68	69, 71	73, 75	82, 84	82, 84
SID Ile:Lys, %	70	60, 58	56	61, 60	70	70
SID Leu:Lys, %	150-170	131, 137	147, 159	153,164	165, 176	165, 176

¹Positive Control (PC): a corn-SBM based diet with SID BCAA:Lys of PIC (2020) for overall experimental period, Negative Control (NC): a cDDGS diet with SID BCAA:Lys of PIC (2020) for overall experimental period, a cDDGS diet with SID BCAA:Lys targeted for the growing phase for overall experimental period (Grow), a cDDGS diet with SID BCAA:Lys targeted for the finishing phase for overall experimental period (Finish), a cDDGS diet with SID BCAA:Lys targeted for the growing phase for Phases 1 and 2 and SID BCAA:Lys targeted for the finishing phase for Phases 3 and 4 (Grow-Finish).

Table 2. Analyzed composition of the major ingredients (as-fed basis)

Item, %	Ingredient		
	Corn	SBM	cDDGS
Moisture	13.56	10.32	11.09
Crude protein	7.30	46.86	30.17
Crude fat	1.76	0.45	6.61
Crude ash	0.96	6.36	4.40
Crude fiber	1.31	2.79	7.48
Neutral detergent fiber	6.86	8.86	31.24
Acid detergent fiber	2.65	5.73	13.47
Indispensable AA			
Arg	0.30	3.39	1.47
His	0.19	1.24	0.85
Ile	0.24	2.29	1.20
Leu	0.78	3.70	3.42
Lys	0.23	3.03	1.07
Met	0.14	0.66	0.56
Phe	0.32	2.38	1.39
Thr	0.24	1.87	1.16
Trp	0.04	0.66	0.23
Val	0.32	2.42	1.55
Dispensable AA			
Ala	0.48	2.07	1.95
Asp	0.45	5.36	1.93
Glu	1.21	8.55	4.00
Gly	0.27	2.01	1.15
Pro	0.59	2.50	2.44
Ser	0.30	2.09	1.31
Tyr	0.19	1.67	1.11

Table 3a. Ingredient and calculated chemical composition of the diets for Phase 1 and 2 (as-fed basis)

Item	Phase 1					Phase 2				
	PC ¹	NC	G	F	GF	PC	NC	G	F	GF
Ingredients, %										
Corn	68.15	50.95	47.56	43.95	47.56	75.89	58.68	55.94	51.30	55.94
Soybean meal	28.30	14.42	17.75	21.42	17.75	20.74	6.93	9.63	14.18	9.63
cDDGS	0.00	30.00	30.00	30.00	30.00	0.00	30.00	30.00	30.00	30.00
Corn oil	0.50	1.67	1.97	2.26	1.97	0.50	1.66	1.91	2.32	1.91
L-lysine	0.31	0.57	0.47	0.35	0.47	0.31	0.57	0.48	0.34	0.48
L-methionine	0.16	0.11	0.08	0.05	0.08	0.11	0.06	0.03	0.00	0.03
L-threonine	0.24	0.25	0.20	0.13	0.20	0.21	0.22	0.17	0.10	0.17
L-tryptophan	0.02	0.07	0.05	0.03	0.05	0.03	0.08	0.06	0.03	0.06
Calcium carbonate	0.98	1.28	1.25	1.28	1.25	0.95	1.27	1.25	1.21	1.25
Monocalcium phosphate	0.65	0.15	0.15	0.00	0.15	0.57	0.00	0.00	0.00	0.00
Salt	0.51	0.34	0.34	0.34	0.34	0.51	0.34	0.34	0.34	0.34
SDSU Vitamin premix ²	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
SDSU Mineral premix ³	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Calculated nutrients										
NE, kcal/kg	2,424.9	2,422.2	2,420.8	2,419.5	2,420.8	2,467.6	2,465.0	2,464.0	2,462.1	2,464.0
Crude protein, %	18.38	19.45	20.58	21.83	20.58	15.39	16.49	17.40	18.94	17.40
SID ⁴ Lys, %	1.142	1.147	1.147	1.147	1.147	0.953	0.957	0.957	0.957	0.957
SID Met+Cys:Lys	0.592	0.594	0.594	0.594	0.594	0.591	0.592	0.593	0.598	0.593
SID Thr:Lys	0.672	0.669	0.669	0.669	0.669	0.673	0.668	0.668	0.669	0.668
SID Trp:Lys	0.210	0.211	0.211	0.211	0.211	0.210	0.210	0.210	0.211	0.210
SID Val:Lys	0.680	0.680	0.729	0.784	0.729	0.681	0.682	0.730	0.811	0.730
SID Leu:Lys	1.197	1.361	1.428	1.504	1.428	1.250	1.449	1.515	1.626	1.515
SID Ile:Lys	0.638	0.586	0.639	0.698	0.639	0.619	0.558	0.610	0.698	0.610
Calcium, %	0.60	0.60	0.60	0.60	0.60	0.55	0.55	0.55	0.55	0.55
Total P, %	0.45	0.47	0.48	0.46	0.48	0.41	0.42	0.43	0.44	0.43
Available P, %	0.35	0.36	0.37	0.35	0.37	0.32	0.32	0.33	0.34	0.33

¹Positive Control (PC): a corn-SBM based diet with SID BCAA:Lys of PIC (2020) for overall experimental period, 2) Negative Control (NC): a cDDGS diet with SID BCAA:Lys of PIC (2020) for overall experimental period; 3) a cDDGS diet with SID BCAA:Lys targeted for the growing phase for overall experimental period (Grow); 4) a cDDGS diet with SID BCAA:Lys targeted for the finishing phase for overall experimental period (Finish); 5) a cDDGS diet with SID BCAA:Lys targeted for the growing phase for Phases 1 and 2 and SID BCAA:Lys targeted for the finishing phase for Phases 3 and 4 (Grow-Finish).

²Provided the following per kilogram of diet: 11,011 IU vitamin A, 1,652 IU vitamin D₃, 55 IU vitamin E, 0.04 mg vitamin B₁₂, 4.4 mg menadione, 9.9 mg riboflavin, 61 mg pantothenic acid, 55 mg niacin, 1.1 mg folic acid, 3.3 mg pyridoxine, 3.3 mg thiamine, and 0.2 mg biotin.

³Provided the following per kilogram of diet: 165 mg Zn as ZnSO₄, 23 mg Fe as FeSO₄, 17 mg Cu as CuSO₄, and 44 mg Mn as MnSO₄.

⁴SID: standardized ileal digestible.

Table 3b. Ingredient and calculated chemical composition of the diets for Phase 3 and 4 (as-fed basis)

Item	Phase 3					Phase 4				
	PC ¹	NC	G	F	GF	PC	NC	G	F	GF
Ingredients, %										
Corn	81.65	69.90	67.77	63.73	63.73	86.28	73.51	71.94	68.02	68.02
Soybean meal	15.17	6.19	8.28	12.36	12.36	10.77	2.82	4.34	8.16	8.16
cDDGS	0.00	20.00	20.00	20.00	20.00	0.00	20.00	20.00	20.00	20.00
Corn oil	0.51	1.32	1.51	1.83	1.83	0.50	1.39	1.53	1.88	1.88
L-lysine	0.30	0.47	0.41	0.28	0.28	0.30	0.44	0.39	0.27	0.27
L-methionine	0.07	0.04	0.02	0.00	0.00	0.04	0.00	0.00	0.00	0.00
L-threonine	0.18	0.18	0.15	0.08	0.08	0.17	0.16	0.13	0.07	0.07
L-tryptophan	0.03	0.06	0.05	0.03	0.03	0.03	0.06	0.05	0.03	0.03
Calcium carbonate	0.91	1.10	1.08	1.10	1.10	0.86	1.06	1.04	1.01	1.01
Monocalcium phosphate	0.47	0.15	0.15	0.00	0.00	0.36	0.00	0.00	0.00	0.00
Salt	0.51	0.40	0.40	0.40	0.40	0.49	0.37	0.37	0.37	0.37
SDSU Vitamin premix ²	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
SDSU Mineral premix ³	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Calculated nutrients										
NE, kcal/kg	2,500.7	2,498.8	2,498.1	2,496.2	2,496.2	2,528.4	2,525.9	2,525.5	2,523.8	2,523.8
Crude protein, %	13.19	14.00	14.70	16.10	16.10	11.46	12.62	13.14	14.45	14.45
SID ⁴ Lys, %	0.813	0.816	0.815	0.816	0.816	0.703	0.706	0.706	0.706	0.706
SID Met+Cys:Lys	0.589	0.590	0.591	0.612	0.612	0.588	0.592	0.610	0.656	0.656
SID Thr:Lys	0.672	0.669	0.669	0.670	0.670	0.682	0.679	0.679	0.679	0.679
SID Trp:Lys	0.209	0.209	0.210	0.210	0.210	0.208	0.209	0.209	0.210	0.210
SID Val:Lys	0.682	0.687	0.731	0.816	0.816	0.682	0.713	0.750	0.842	0.842
SID Leu:Lys	1.306	1.468	1.528	1.646	1.646	1.366	1.587	1.637	1.763	1.763
SID Ile:Lys	0.600	0.558	0.605	0.697	0.697	0.579	0.557	0.597	0.696	0.696
Calcium, %	0.50	0.500	0.50	0.50	0.50	0.45	0.45	0.45	0.45	0.45
Total P, %	0.370	0.39	0.40	0.38	0.38	0.33	0.35	0.35	0.36	0.36
Availble P, %	0.29	0.31	0.31	0.29	0.29	0.27	0.27	0.28	0.28	0.28

¹Positive Control (PC): a corn-SBM based diet with SID BCAA:Lys of PIC (2020) for overall experimental period, 2) Negative Control (NC): a cDDGS diet with SID BCAA:Lys of PIC (2020) for overall experimental period; 3) a cDDGS diet with SID BCAA:Lys targeted for the growing phase for overall experimental period (Grow); 4) a cDDGS diet with SID BCAA:Lys targeted for the finishing phase for overall experimental period (Finish); 5) a cDDGS diet with SID BCAA:Lys targeted for the growing phase for Phases 1 and 2 and SID BCAA:Lys targeted for the finishing phase for Phases 3 and 4 (Grow-Finish).

²Provided the following per kilogram of diet: 11,011 IU vitamin A, 1,652 IU vitamin D₃, 55 IU vitamin E, 0.04 mg vitamin B₁₂, 4.4 mg menadione, 9.9 mg riboflavin, 61 mg pantothenic acid, 55 mg niacin, 1.1 mg folic acid, 3.3 mg pyridoxine, 3.3 mg thiamine, and 0.2 mg biotin.

³Provided the following per kilogram of diet: 165 mg Zn as ZnSO₄, 23 mg Fe as FeSO₄, 17 mg Cu as CuSO₄, and 44 mg Mn as MnSO₄.

⁴SID: standardized ileal digestible.

Table 4. Growth performance of growing-finishing pigs fed the cDDGS diets with different SID BCAA:Lys ratio adjusted by SBM inclusion.

Item	Treatment ¹					SEM ²	P-value
	PC	NC	Grow	Finish	Grow-Finish		
Body weight (BW), kg							
Initial	28.9	28.7	28.7	28.7	28.7	0.70	0.999
Phase 1	48.9	48.5	48.7	49.2	48.7	0.84	0.986
Phase 2	80.2	78.2	79.1	80.6	79.2	0.99	0.496
Phase 3	101.8	100.3	100.3	103.5	100.1	1.02	0.110
Phase 4	110.0 ^{xy}	107.9 ^y	107.3 ^y	111.4 ^x	107.3 ^y	1.20	0.064
Average daily gain (ADG), g/d							
Phase 1	951	944	954	976	951	19.6	0.824
Phase 2	1116 ^a	1062 ^b	1086 ^{ab}	1122 ^a	1091 ^{ab}	14.4	0.038
Phase 3	1032 ^{ab}	1052 ^{ab}	1010 ^b	1090 ^a	991 ^b	21.6	0.023
Phase 4	1371	1256	1157	1328	1208	61.4	0.111
Overall	1067 ^{ab}	1042 ^b	1034 ^b	1089 ^a	1034 ^b	13.6	0.023
Average daily feed intake (ADFI), g/d							
Phase 1	1843	1781	1782	1816	1795	33.0	0.636
Phase 2	2463	2503	2443	2511	2511	59.5	0.891
Phase 3	3072 ^a	3106 ^a	3016 ^a	3132 ^a	2860 ^b	49.6	0.003
Phase 4	3196	3196	3236	3334	3331	58.1	0.243
Overall	2527	2533	2491	2565	2485	34.2	0.459
Gain to feed ratio (G:F)							
Phase 1	0.516	0.530	0.536	0.537	0.531	0.0064	0.164
Phase 2	0.458	0.425	0.446	0.449	0.434	0.0117	0.314
Phase 3	0.336	0.339	0.335	0.349	0.347	0.0060	0.322
Phase 4	0.430 ^x	0.392 ^{xy}	0.358 ^y	0.399 ^{xy}	0.363 ^y	0.0186	0.060
Overall	0.423	0.411	0.416	0.425	0.416	0.0051	0.325

^{ab} Within a row, means without a common superscript differ ($P < 0.05$).

^{xy} Within a row, means without a common superscript show tendency to differ ($P < 0.10$).

*Phase 1: 0 to 3 weeks, Phase 2: 3 to 7 weeks, Phase 3: 7 to 10 weeks, and Phase 4: 10 to 11 weeks.

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²Standard error of the means.

Table 5. Carcass traits of growing-finishing pigs fed the cDDGS diets with different SID BCAA:Lys ratio adjusted by SBM inclusion.

Item	Treatment ¹					SEM ²	P-value
	PC	NC	Grow	Finish	Grow-Finish		
No. of head, n	216	223	223	221	223		
BW at slaughter, kg	118.0 ^{ab}	117.0 ^{ab}	114.0 ^b	121.6 ^a	114.9 ^b	1.70	0.019
Hot carcass weight, kg	89.2	88.9	88.0	88.6	89.1	0.72	0.778
Carcass yield, %	77.4	76.3	77.6	73.0	78.0	1.52	0.139
Iodine value ³	67.04 ^c	77.43 ^b	78.19 ^b	80.61 ^a	77.96 ^b	0.433	<.001

^{abc} Within a row, means without a common superscript differ ($P < 0.05$).

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²Standard error of the means.

³Iodine values were investigated from 36 carcasses within the second and third market groups.

Table 6. Plasma urea nitrogen (PUN) concentration of growing-finishing pigs fed the cDDGS diets with different SID BCAA:Lys ratio adjusted by SBM inclusion.

Item	Treatment ¹					SEM ²	P-value
	PC	NC	Grow	Finish	Grow-Finish		
PUN, mg/dL							
Phase 2 ³	10.43 ^b	9.18 ^b	9.65 ^b	15.00 ^a	10.32 ^b	0.740	<.001
Phase 4 ⁴	12.86	11.14	12.64	12.98	12.85	0.952	0.623

^{ab} Within a row, means without a common superscript differ ($P < 0.05$).

¹Positive Control (PC): a corn-SBM based diet with SID BCAA:Lys of PIC (2020) for overall experimental period; 2) Negative Control (NC): a cDDGS diet with SID BCAA:Lys of PIC (2020) for overall experimental period; 3) a cDDGS diet with SID BCAA:Lys targeted for the growing phase for overall experimental period (Grow); 4) a cDDGS diet with SID BCAA:Lys targeted for the finishing phase for overall experimental period (Finish); 5) a cDDGS diet with SID BCAA:Lys targeted for the growing phase for Phases 1 and 2 and SID BCAA:Lys targeted for the finishing phase for Phases 3 and 4 (Grow-Finish).

²Standard error of the means.

³At the end of 7 weeks

⁴At the end of 13 weeks

Table 7. Plasma amino acid profile of growing-finishing pigs fed the cDDGS diets with different SID BCAA:Lys ratio adjusted by SBM inclusion (Phase 2; At the end of 7 weeks).

Item	Treatment ¹					SEM ²	P-value
	PC	NC	Grow	Finish	Grow-Finish		
Indispensable amino acids, umol/L							
Arg	88.9 ^{xy}	68.3 ^y	66.9 ^y	93.9 ^x	72.3 ^{xy}	7.68	0.053
His	50.4 ^b	53.6 ^b	61.3 ^a	62.1 ^a	55.9 ^{ab}	2.50	0.009
Ile	64.4 ^a	43.0 ^b	44.4 ^b	66.9 ^a	49.6 ^b	3.45	<.001
Leu	131.7 ^b	163.3 ^a	161.5 ^a	182.7 ^a	181.9 ^a	7.43	<.001
Lys	217.8	240.3	184.6	194.4	192.1	20.16	0.288
Met	26.4	25.6	23.5	22.0	24.3	1.19	0.113
Phe	43.1 ^b	43.2 ^b	45.5 ^b	54.7 ^a	47.3 ^b	2.07	0.002
Thr	175.0 ^a	148.7 ^{ab}	133.5 ^b	138.2 ^b	134.5 ^b	9.48	0.019
Trp	6.7	8.0	7.0	8.1	7.7	0.82	0.704
Val	144.8 ^{ab}	111.2 ^c	116.2 ^c	168.0 ^a	129.6 ^{bc}	9.71	0.001
Dispensable amino acids, umol/L							
Ala	408.9 ^a	406.8 ^a	348.4 ^{ab}	328.0 ^b	411.4 ^a	21.7	0.021
Asp	24.5	26.0	22.3	22.6	25.5	2.04	0.635
Glu	199.6 ^{bc}	251.3 ^{ab}	205.0 ^{bc}	178.3 ^c	265.8 ^a	19.75	0.017
Gly	873.3 ^b	986.6 ^a	902.1 ^{ab}	770.7 ^c	915.8 ^{ab}	34.77	0.002
Pro	214.1	244.0	241.2	244.3	268.8	14.03	0.128
Ser	141.0	142.2	126.8	139.8	136.9	7.76	0.634
Tyr	79.0 ^c	82.2 ^{bc}	87.8 ^{abc}	96.2 ^a	89.1 ^{ab}	3.18	0.005

^{abc} Within a row, means without a common superscript differ ($P < 0.05$).

^{xy} Within a row, means without a common superscript show tendency of differ ($P < 0.10$).

¹Positive Control (PC): a corn-SBM based diet with SID BCAA:Lys of PIC (2020) for overall experimental period; 2) Negative Control (NC): a cDDGS diet with SID BCAA:Lys of PIC (2020) for overall experimental period; 3) a cDDGS diet with SID BCAA:Lys targeted for the growing phase for overall experimental period (Grow); 4) a cDDGS diet with SID BCAA:Lys targeted for the finishing phase for overall experimental period (Finish); 5) a cDDGS diet with SID BCAA:Lys targeted for the growing phase for Phases 1 and 2 and SID BCAA:Lys targeted for the finishing phase for Phases 3 and 4 (Grow-Finish).

²Standard error of the means.

Table 8. Plasma amino acid profile of growing-finishing pigs fed the cDDGS diets with different SID BCAA:Lys ratio adjusted by SBM inclusion (Phase 4; At the end of 13 weeks).

Item	Treatment ¹					SEM ²	P-value
	PC	NC	Grow	Finish	Grow-Finish		
Indispensable amino acids, umol/L							
Arg	97.7 ^a	82.6 ^b	81.0 ^b	100.8 ^a	101.4 ^a	4.75	0.004
His	42.7 ^c	48.8 ^{bc}	57.3 ^a	52.8 ^{ab}	56.0 ^{ab}	2.50	0.001
Ile	48.4 ^{ab}	41.4 ^b	42.1 ^b	53.2 ^a	47.0 ^{ab}	2.54	0.013
Leu	129.9 ^b	153.0 ^a	151.0 ^a	157.6 ^a	153.5 ^a	5.30	0.006
Lys	222.0 ^a	210.8 ^{ab}	205.0 ^{ab}	181.8 ^{bc}	166.7 ^c	12.12	0.021
Met	28.9 ^a	23.3 ^b	26.9 ^a	25.3 ^{ab}	25.4 ^{ab}	1.27	0.043
Phe	41.9	40.6	41.5	47.5	44.0	2.02	0.138
Thr	144.8 ^x	138.7 ^x	128.4 ^{xy}	128.6 ^{xy}	114.2 ^y	7.44	0.073
Trp	4.42	4.06	4.23	4.16	4.14	0.34	0.953
Val	132.6 ^y	127.4 ^y	123.9 ^y	153.0 ^x	135.3 ^{xy}	7.00	0.051
Dispensable amino acids, umol/L							
Ala	358.9 ^a	301.8 ^{bc}	341.1 ^{ab}	293.5 ^c	319.0 ^{abc}	16.16	0.038
Asp	23.5	21.5	26.1	21.6	29.4	2.37	0.130
Glu	152.2	168.3	184.2	140.1	188.4	15.71	0.177
Gly	710.7 ^c	812.6 ^{abc}	865.9 ^a	723.9 ^{bc}	844.6 ^{ab}	42.37	0.036
Pro	179.1 ^b	212.0 ^{ab}	229.6 ^a	217.5 ^a	223.5 ^a	11.56	0.035
Ser	114.6	134.1	127.1	130.0	126.3	6.82	0.352
Tyr	78.2	83.0	85.0	90.2	87.4	3.41	0.159

^{abc} Within a row, means without a common superscript differ ($P < 0.05$).

^{xy} Within a row, means without a common superscript show tendency of differ ($P < 0.10$).

¹Positive Control (PC): a corn-SBM based diet with SID BCAA:Lys of PIC (2020) for overall experimental period; 2) Negative Control (NC): a cDDGS diet with SID BCAA:Lys of PIC (2020) for overall experimental period; 3) a cDDGS diet with SID BCAA:Lys targeted for the growing phase for overall experimental period (Grow); 4) a cDDGS diet with SID BCAA:Lys targeted for the finishing phase for overall experimental period (Finish); 5) a cDDGS diet with SID BCAA:Lys targeted for the growing phase for Phases 1 and 2 and SID BCAA:Lys targeted for the finishing phase for Phases 3 and 4 (Grow-Finish).

²Standard error of the means.

Table 9. Economic performance of growing-finishing pigs fed the cDDGS diets with different SID BCAA:Lys ratio adjusted by SBM inclusion.

Item	Treatment ¹					SEM ²	P-value
	PC	NC	Grow	Finish	Grow-Finish		
Feed cost, \$/tonne							
Phase 1	300.9	285.8	286.9	286.8	286.9		
Phase 2	287.5	271.7	272.6	274.4	272.6		
Phase 3	277.3	267.4	268.2	268.9	268.9		
Phase 4	269.3	259.5	260.6	263.3	263.3		
Output, \$/pig							
Carcass gain value ³	196.7	196.1	194.1	195.4	196.4	1.58	0.777
Input, \$/pig							
Total feed cost ⁴	68.8	67.3	65.9	68.1	68.0	0.97	0.288
Facility cost ⁵	8.9	8.8	8.8	8.9	8.9	0.03	0.176
Net income, \$/pig							
IOFC ⁶	128.0	128.8	128.2	127.4	128.4	1.79	0.986
IOFFC ⁷	119.1	120.0	119.4	118.5	119.5	1.80	0.984

^{abc} Within a row, means without a common superscript differ ($P < 0.05$).

^{xyz} Within a row, means without a common superscript show tendency of differ ($P < 0.10$).

¹Positive control (PC): a corn-SBM based diet with SID BCAA:Lys of PIC (2020) for overall experimental period; negative control (NC): a cDDGS diet with SID BCAA:Lys of PIC (2020) for overall experimental period; Grow: a cDDGS diet with SID BCAA:Lys targeted for the growing phase for overall experimental period; Finish: a cDDGS diet with SID BCAA:Lys targeted for the finishing phase for overall experimental period; Grow-Finish: a cDDGS diet with SID BCAA:Lys targeted for the growing phase for phases 1 and 2 and SID BCAA:Lys targeted for the finishing phase for phases 3 and 4.

²Standard error of the means.

³Average carcass gain value from first pigs loading (11 weeks) to last pigs loading (14 weeks).

⁴Feed cost x total feed consumption from initial to last loading (14 weeks).

⁵Facility cost at \$0.10/hd/day (until last loading; 14 weeks).

⁶Income over feed cost = carcass gain value – total feed cost.

⁷Income over feed and facility cost = IOFC – facility cost.