Title: Improving performance of finishing pigs with supplemental Val, Ile, and Trp: Validating a meta-analysis model. **NPB #19-078**

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Industry Summary: Branched-chain amino acids (BCAA) are a collective group of amino acids (AA) made up of Leucine (Leu), Valine (Val), and Isoleucine (Ile). These three AA all share the first steps of catabolism, and an excess of one can lead to increased catabolism of all BCAA. Other AA such as Tryptophan (Trp) also interact with BCAA in normal metabolism. Finishing pig diets containing DDGS are often formulated with high inclusions of Lys-HCl and low soybean meal which leads to higher than optimum levels of Leu in relation to Val, Ile, and Trp. A recent meta-analysis (Cemin, 2019) suggested that high Leu diets require higher than normal ratios of Val, Ile, and Trp in order to maintain growth performance. However, data was not available to confirm this hypothesis and consequently two trials were conducted to determine if increasing the level of added Val, Ile, and Trp in low SBM/high Lys-HCl diets that have high Leu would improve performance of grow finish pigs. In the first trial a control diet with DDGS, higher SBM and low Lys-HCl was compared to DDGS-containing diets with lower SBM and higher Lys-HCl that were supplemented with higher levels of Val, Ile, and/or Trp. This study confirmed the negative impact on growth performance from diets with high levels of Leu when low levels of Val, Ile, and Trp were also present. However, supplementing increased levels of Val and Ile improved performance. The meta-analysis model was relatively accurate in predicting the performance of the pigs in this study. In the second trial a control diet with higher SBM and low Lys-HCl was compared to three diets with low SBM and high Lys-HCl with low, medium, or high ratios of Val, Ile, and Trp in relation to Leu. In this trial, the low ratio was close to published requirements of pigs, the medium ratio was slightly higher than those typically used to maximize growth performance, and the high ratio was much higher than typical commercial diets. Results showed that increasing the ratios of Val, Ile, and Trp from low to medium improved performance, but no additional benefit was observed from going to high supplementation levels. The prediction model was relatively accurate in predicting the performance of the medium ratio treatment but overestimated the performance of the high ratio treatment. This data suggests that increased supplementation of Val, Ile, and Trp are needed to improve growth performance when low SBM/high Lys-HCl diets that contain elevated Leu are fed, but high supplementation levels do not provide additional benefit. Collectively these trials show that when DDGS diets are fed that contain low SBM and high inclusions of Lys-HCl, the combination of high Leu and low Val, Ile, and Trp will result in poorer performance. Increasing the Val, Ile, and Trp to levels higher than typically formulated will restore performance. These trials provide solutions to producers to take advantage of lower diet costs when feeding DDGS diets with low SBM and high Lys-HCl in order to maintain growth performance similar to a higher priced diet containing higher levels of SBM. For more information, contact Dr. Jason Woodworth (JWoodworth@ksu.edu).

Key Findings:

- Diets containing DDGS and high Lys-HCl with low SBM will result in pig growth performance lower than that observed with higher SBM diets, most likely as a result of an imbalance of branch chain amino acids.
- A recent meta-analysis resulted in a prediction equation that estimates growth performance based on the dietary concentrations of Leu, Val, Ile, and Trp.
- These trials helped validate the prediction equation and show that when increased concentrations of Leu are present in the diet, higher than normal levels of Val, Ile, and Trp are needed to optimize finishing pig growth performance.
- This data illustrates an opportunity for producers to take advantage of lower diet costs when feeding DDGS diets with low SBM and high Lys-HCl in order to maintain growth performance similar to a higher priced diet containing higher levels of SBM.

Keywords: Swine, Leucine, Isoleucine, Valine, Tryptophan

Scientific Abstract: A recent meta-analysis (Cemin, 2019) suggested that increased dietary Val, Ile, or Trp could correct possible amino acid interactions caused by high dietary Leu in diets containing high levels of DDGS. We conducted two experiments to confirm this hypothesis. For Exp. 1, 1,200 pigs (PIC TR4 × (Fast LW × PIC L02); initially 74.0 ± 1.38 lb) were used in a 103-d study. The 6 dietary treatments were corn-soybean meal-DDGS-based diets as follows: 1) low level of Lys-HCl (HSBM), 2) high Lys-HCl and moderate Ile, Val, Trp (NC; AA above NRC 2012 estimates), 3) moderate Lys-HCl and high Ile, Val, Trp (PC), and 4) PC with either increased L-Val (PC+Val), 5) L-Ile (PC+Ile), or 6) L-Trp (PC+Trp). Diets contained 30% DDGS until pigs reached approximately 217 lb, and then were fed diets with 20% DDGS until market. In the grower period, ADG was greater ($P < 0.05$) for the pigs fed HSBM and PC+Val diets than the NC with PC, PC+Ile, and PC+Trp intermediate. Pigs fed HSBM were more ($P < 0.05$) efficient than the NC and PC with PC+Val, PC+Ile, and PC+Trp being intermediate. In the late finisher period, ADG was greater ($P < 0.05$) for pigs fed PC+Ile than that of the NC with HSBM, PC, PC+Val, and PC+Trp intermediate. Pigs fed PC+Val had greater ($P < 0.05$) ADFI than the NC with HSBM, PC, PC+Ile, and PC+Trp being intermediate. However, PC+Ile pigs were more ($P < 0.05$) efficient than PC+Val pigs with HSBM, NC, PC, and PC+Trp being intermediate. Overall, final body weight (BW), average daily gain (ADG), and hot carcass weight (HCW) were greater ($P < 0.05$) for pigs fed HSBM, PC+Val, and PC+Ile diets than the NC with PC and PC+Trp intermediate. Pigs fed the PC+Val diet had greater ($P < 0.05$) average daily feed intake (ADFI) than the NC with pigs fed HSBM, PC, PC+Ile, and PC+Trp intermediate. No differences were detected between treatments for overall F/G or other carcass characteristics. The meta-analysis model was relatively accurate in predicting the performance of the pigs in this study.

In Exp. 2, 1,916 finishing pigs (PIC TR4 × (Fast LW × PIC L02); PIC< Hendersonville, TN, USA; Fast Genetics, Saskatoon, SK, Canada; Initial BW 90.8 ± 0.1) were used in a 106-d growth trial. Pens were assigned to 1 of 4 dietary treatments with 25 replicate pens per treatment. The 4 corn/SBM/DDGS-based treatments were: 1) high SBM and low feed grade AA diet, 2) low SBM and high feed grade with low ratios of Val:Lys, Ile:Lys and Trp:Lys, 3) low SBM and high feed grade AA diet with medium ratios of Val:Lys, Ile:Lys and Trp:Lys, and 4) low SBM and high feed grade AA diet with high ratios of Val:Lys, Ile:Lys and Trp:Lys. In this trial, the low ratio was close to published requirements of pigs, the medium ratio was slightly higher than those typically used to maximize growth performance, and the high ratio was much higher than typical commercial diets. Overall, increasing the ratios of Ile, Val, and Trp tended to increase ADG (Quadratic, $P = 0.084$), ADFI (Linear, $P = 0.060$), and improve (Quadratic, $P = 0.087$) F/G, with the best performance observed from pigs fed the medium ratio treatment. For carcass characteristics, there was a tendency (Quadratic, $P = 0.080$) for reduced Lean% as the

ratios of Ile, Val, and Trp increased, but no other impacts on carcass characteristics were observed. The prediction model was relatively accurate in predicting the performance of the medium ratio treatment but overestimated the performance of the high ratio treatment.

Across both trials, this data suggests that increasing Val, Ile, and Trp in high Lys-HCl-DDGS-based diets that have low levels of SBM improved growth performance and final BW. These results demonstrate that the negative effects of high Leu in corn-DDGS-based diets can be overcome by increasing the ratios of Val, Ile, and Trp to Lys and provide a solution to producers to take advantage of lower diet costs without losing performance.

Introduction:
Branched-chain amino acids (BCAA) are a collective group of amino acids (AA) made up of Leu, Val, and Ile. These three AA all share the first steps of catabolism, and an excess of one can lead to increased catabolism of all BCAA. Leucine, the most potent stimulator of the catabolism, is disproportionally higher in corn than Val and Ile, thus resulting in an imbalance in BCAA when high levels of corn and corn byproducts are used in swine diets. The BCAA also compete with large neutral amino acids (LNAA), such as Trp, for the same transporters by the brain. Tryptophan is a precursor of serotonin, which plays a key role in feed intake regulation, and an excess in Leu can result in a decreased Trp in the brain, which ultimately can lead to a reduction in feed intake. Currently, there is an incentive to reduce diet cost with the use of high levels of feed grade AA, which allows for the reduction of soybean meal (SBM) in the diet and the ability to use more corn and corn byproducts in place of SBM. This scenario, however, leads to an imbalance in BCAA and potentially a reduction in growth performance.

Based on an extensive literature review, Cemin (2019) developed a model that suggests the decrease in performance can be prevented with the inclusion of different combinations of Ile, Val, and/or Trp. If this model is correct, it will create a platform for further advancements in diet formulation, which will allow nutritionists to create more economical diets while maintaining or potentially increasing performance. However, data is not available to determine the accuracy of the prediction model.

Objectives:
The overall objective of this set of trials is to validate a growth-predicting model and determine if supplementing Val, Ile, and/or Trp will improve the growth performance of pigs fed diets with high Lys-HCl (low SBM) similar to growth performance of pigs fed diets with low Lys-HCl inclusions. The specific objectives for both trials are:

- Trial 1: To validate the growth performance predictions of a newly developed model suggesting the level of supplemental Val, Ile, or Trp required to ameliorate the poor performance of pigs fed diets containing high levels of Lys-HCl.
- Trial 2: To further validate the model by determining economical combinations of supplemental Val, Ile, and/or Trp to ameliorate the poor performance of pigs fed diets containing high levels of Lys-HCl.

Materials & Methods:
General: The Kansas State University Institutional Animal Care and Use Committee approved the protocols used in these experiments. The study was conducted at a commercial research-finishing site in southwest Minnesota (New Fashion Pork, Jackson, MN). The barns were tunnel-ventilated with completely slatted concrete flooring and deep pits for manure storage. Each pen (8 × 19 ft) was equipped with adjustable gates and contained a 3-hole, dry feeder (Thorp Equipment, Inc., Thorp, WI) and a pan waterer for *ad libitum* access to feed and water. Feed additions were delivered and recorded using a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN).

Exp. 1: A total of 1,200 finishing pigs (PIC TR4 × (Fast LW × PIC L02); PIC, Hendersonville, TN, USA; Fast Genetics, Saskatoon, SK, Canada; initial BW 74.0 ± 1.39) were used in a 103-d growth trial. Pigs were housed in mixed gender pens with 20 pigs per pen and 10 replicates per treatment. Pens were assigned to 1 of 6 dietary treatments in a complete randomized block design with initial BW and pen location within barn as blocking factors. Experimental diets (Tables 1 and 2) were:

1. high SBM and low feed grade AA (HSBM) with Val:Lys, Ile:Lys and Trp:Lys ranging from 85 to 90, 76 to 78, and 19.3 to 19.9, respectively, across the 4 dietary phases.
2. negative control (NC) with high levels of feed grade AA and low SBM with Val:Lys, Ile:Lys and Trp:Lys ranging from 64 to 68, 51 to 53, and 17.0 to 17.5, respectively, across the 4 dietary phases.
3. positive control (PC) with a medium feed grade AA inclusion with Val:Lys and Trp:Lys held constant at 70 and 19.0, respectively, and with Ile:Lys ranging from 58 to 61 across the 4 dietary phases.
4. PC with high Val:Lys (PC+Val) ranging from 76 to 80 across the 4 dietary phases.
5. PC with a high Ile:Lys (PC+Ile) ranging from 66 to 68 across the 4 dietary phases.
6. PC with a high Trp:Lys (PC+Trp) ranging from 21.1 to 23.1 across the 4 dietary phases.

The PC+Val and PC+Trp treatments were developed by increasing the Val:Lys and Trp:Lys, respectively, until the model predicted the same ADG of the HSBM treatment. The PC+Ile treatment was created by increasing the Ile:Lys until the predicted ADG was maximized. Since the model predicts that the response to Ile is quadratic, the optimal level is unable to match the predicted ADG of the HSBM diet.

Experimental diets were fed in 4 phases from d 0 to 16, 16 to 40, 40 to 64, and 64 to 103, which correspond to body weights of approximately 74 to 112, 112 to 165, 165 to 217, and 217 lb to market, respectively. Experimental diets were corn-SBM-DDGS-based with 30% DDGS fed in phases 1 to 3 and 20% DDGS fed in phase 4.

Each pig was tagged with an RFID tag at the beginning of the trial in order to be individually identified. Pigs were weighed approximately every 14 days to determine ADG, ADFI, and F/G. On d 83, four to six of the heaviest pigs in each pen were selected and marketed, with a consistent inventory of 14 pigs remaining in each pen. The pigs marketed on d 83 were included in the growth data, but not in the final pen carcass data. On the last day of the trial, final pen weights were measured and the remaining pigs were identified by RFID tags and transported to a U.S. Department of Agriculture-inspected packing plant (Triumph Foods, St. Joseph, MO) for carcass data collection. Carcass measurements included hot carcass weight (HCW), loin depth, backfat, and percentage lean. Percentage lean was calculated from a plant proprietary equation. Carcass yield was calculated by dividing the pen average HCW by the pen average final live weight obtained at the farm.

In order to validate and compare the predicted ADG model to the actual ADG that occurred in the experiment, the equation's intercept term was adjusted until the predicted ADG matched the actual ADG for the pigs fed the HSBM diets. The equation with the adjusted intercept term was then used to predict the ADG of the remaining five treatments. The relationship between the actual and predicted ADG was calculated (actual ADG/predicted ADG) to illustrate the accuracy of the prediction model.

For the economic evaluation, feed cost per pig, feed cost per pound of gain, revenue, and income over feed cost (IOFC) were calculated. The ingredient prices used were: corn ($0.070/lb), SBM ($0.151/lb), DDGS ($0.073/lb), L-Lys ($0.681/lb), L-Trp ($2.564/lb), L-

Ile($4.764/lb), and L-Val ($1.200/lb). Feed cost was calculated by total diet cost multiplied by total feed consumed per pen and then divided by total days pigs were in pens. Feed cost per lb of gain was calculated by total feed cost per pen divided by total gain per pen. Revenue was calculated by total pen gain multiplied by pen yield and then multiplied by $0.65. Income over feed cost was calculated by taking revenue minus feed cost.

Data were analyzed as a randomized complete block design for one-way ANOVA using the lmer function from the lme4 package in R (version 3.5.1 (2018-07-02), R Foundation for Statistical Computing, Vienna, Austria) with pen considered as the experimental unit, body weight and pen location within barn as blocking factors, and treatment as a fixed effect. Preplanned pairwise comparisons using the Tukey-Kramer adjustment were used to evaluate differences in treatment means. Results were considered significant at $P \leq 0.05$.

Exp. 2: A total of 1,916 finishing pigs (PIC TR4 × (Fast LW × PIC L02); PIC< Hendersonville, TN, USA; Fast Genetics, Saskatoon, SK, Canada; Initial BW 90.8 ± 0.1) were used in a 106-d growth trial. Pigs were housed in two barns in mixed gender pens with approximately 20 pigs per pen and 25 replicates per treatment. Pens were assigned to 1 of 4 dietary treatments in a complete randomized block design with initial BW within each barn as blocking factor. Experimental diets (Tables 5 and 6) were:

1. Control: high soybean meal and low feed grade AA with, Val:Lys, Ile:Lys and Trp:Lys ranging from 92 to 95, 79 to 83, and 23.0, respectively, across the 4 dietary phases.
2. Low ratio: low soybean meal and high feed grade amino acids, with Val:Lys, Ile:Lys and Trp:Lys held constant at 67, 55, and 18.0, respectively, across the 4 dietary phases.
3. Medium ratio: low soybean meal and high feed grade amino acids, with Val:Lys, Ile:Lys, and Trp:Lys held constant at 72, 60, and 21.0, respectively, across the 4 dietary phases.
4. High ratio: low soybean meal and high feed grade amino acids, with Val:Lys, Ile:Lys, and Trp:Lys held constant at 80, 65, and 23.0, respectively, across the 4 dietary phases.

All diets were manufactured at New Fashion Pork commercial feed mill in Estherville, IA. Amino acid hand packs were made for each treatment for all 4 phases. The hand add packs consisted of all of the amino acids and small parts corn for more accurate mixing of amino acids into the rest of the diet. Experimental diets were fed in 4 phases and fed from d 0 to 28, 28 to 56, 56 to 84, and 84 to 107 in barn 1 and from d 0 to 15, 15 to 43, 43 to 71, and 71 to 106 in barn 2, respectively. Experimental diets were corn-SBM_DDGS-based with 30% DDGS fed in phases 1 to 3 and 20% DDGS fed n phase 4.

Pigs were weighed approximately every 14 days to determine ADG, ADFI, and F/G. On d 84 in barn 1 and d 85 in barn 2, four to six of the heaviest pigs in each pen were selected and marketed for first cuts in the barns. The pigs marketed on d 84 and 85 were included in the growth data, but not in the final pen carcass data. On the last day of the trial, final pen weights were measured, and the remaining pigs were identified by RFID tags and transported to a U.S. Department of Agriculture0inspected packing plant (Triumph Foods, St. Joseph, MO) for carcass data collection. Carcass measurements included hot carcass weight (HCW), loin depth, backfat, and percentage lean. Percentage lean was calculated from a plant proprietary equation. Carcass yield was calculated by dividing the pen average HCW by the pen average final live weight obtained at the farm.

Data were analyzed as a randomized complete block design for one-way ANOVA using the lmer function from the lme4 package in R (version 3.5.1 (2018-07-02), R Foundation for Statistical Computing, Vienna, Austria) with pen considered as the experimental unit, body weight as blocking factor, and treatment as a fixed effect. Linear and quadratic contrasts were measured based on the sum of Ile:lys, Val:lys, and Trp:lys as a ratio to Leu:lys within each phase for the Low, Medium and High ratio treatments. Preplanned pairwise comparisons using the Tukey-Kramar adjustment were used to evaluate differences in treatment means. Results were considered significant at $P \leq 0.05$.

Results:

Exp. 1: In the grower period, from 74 to 200 lb, pigs fed the HSBM and PC+Val diets had greater ($P < 0.05$) ADG than the NC pigs, with the PC, PC+Ile, and PC+Trp intermediate (Table 3). The HSBM pigs were also more ($P < 0.05$) efficient than the NC and PC pigs, with PC+Val, PC+Ile, and PC+Trp intermediate. There was no difference ($P > 0.05$) in ADFI among pigs fed any of the treatments during the grower period.

During the finishing period from 200 lb to marketing (approximately 300 lb), ADG was greater ($P < 0.05$) for pigs fed PC+Ile than ADG of the NC, with the HSBM, PC, PC+Val, and PC+Trp being intermediate. Pigs fed PC+Val had greater ($P < 0.05$) ADFI than the NC with HSBM, PC, PC+Ile, and PC+Trp being intermediate. Pigs fed the PC+Ile treatment were more ($P < 0.05$) efficient than PC+Val pigs with HSBM, NC, PC, and PC+Trp being intermediate.

Overall, pigs fed the HSBM, PC+Val, and PC+Ile diets had greater ($P < 0.05$) ADG and ($P < 0.05$) final BW than the pigs fed the NC diet with the PC and PC+Trp being intermediate. Pigs fed the PC+Val diets had greater ($P < 0.05$) ADFI than the NC with pigs fed HSBM, PC, PC+Ile, and PC+Trp being intermediate. There were no significant differences ($P > 0.05$) between treatments for F/G. Similar to overall ADG and final BW, pigs fed the HSBM, PC, PC+Val, and PC+Ile diets had heavier ($P < 0.05$) HCW than the pigs fed the NC diet with the PC+Trp being intermediate. There was no evidence for treatment differences ($P > 0.05$) observed for any other carcass characteristic or percentage carcass yield.

In the economic analysis, pigs fed the HSBM and PC+Ile had the highest ($P < 0.05$) feed cost per pig placed, whereas the NC had the least expensive feed cost, and the PC, PC+Val, and PC+Trp had intermediate feed cost. Pigs fed the HSBM and PC+Val had higher ($P < 0.05$) revenue per pig than the NC, with the PC, PC+Ile, PC+Trp being intermediate. There were no differences ($P > 0.05$), however, for IOFC amongst all the treatments. This economic analysis should be viewed as an example of how to economically compare the treatments because changes in ingredient pricing will influence which dietary option is more economical. For instance, feed grade Ile has limited commercial availability, but when an increased supply is available, the price is expected to decrease allowing for an Ile option that may be more economically attractive. It is recommended that producers utilize their own current ingredient prices to economically compare these treatment options.

To assess the accuracy of the model to the actual performance, we first adjusted the intercept of the predicted HSBM treatment to match the actual ADG. Then, when comparing the predicted ADG from the model to actual ADG in the grower period (Table 4), the model slightly over predicted the ADG (0.5 to 2.6%) for the pigs fed the NC, PC, PC+Val, and PC+Ile diets and over predicted ADG by 3.1% for the PC+Trp pigs. In the finisher period, the model over predicted the ADG for the PC+Val and PC+Trp diets by 0.4 and 1.6%, but under predicted for pigs fed the NC, PC and PC+Ile diets by 2.7, 2.5, and 3.0%, respectively. Overall, the model was quite accurate for most treatments with ADG of the pigs fed the NC, PC, PC+Val and PC+Ile being predicted within 0.4% of actual. The model over predicted ADG of pigs fed the PC+Trp diet by 2.2% relative to the control. The over prediction of the PC+Trp diet by the model could be caused by the model under-predicting the amount of Trp required to improve performance or the potential need for another BCAA to be included in addition to Trp in order to reduce the negative effects of excess Leu.

Exp. 2: In Phase 1, ADG and ADFI increased (Linear, $P < 0.05$) and F/G improved (Quadratic, $P < 0.05$) as ratios of Ile, Val, and Trp were increased (Table 7). Pigs fed the low ratio treatment had the poorest ($P < 0.05$) ADG and F/G compared to the other treatments, while pigs fed the control treatment also had better ($P < 0.05$) F/G compared to those fed the High ratio treatment. In Phase 2, ADFI increased (Linear, $P < 0.05$) as Ile, Val, and Trp ratios increased, but no other differences in performance were observed.

In Phase 3, pigs fed the control diet had the highest ($P < 0.05$) ADG and those fed the lowest ratio had the poorest ADG, with medium and high ratio-fed pigs being intermediate. In Phase 4, increasing the ratios of Ile, Val, and Trp tended to increase (Linear, $P < 0.07$) F/G. Pigs fed the low and medium ratio diets had higher ($P < 0.05$) ADG compared to the control fed pigs, with those fed the high ratios being intermediate. Pigs fed the Control treatment had poorer ($P < 0.05$) F/G compared to those fed the low ratio treatment with pigs fed the medium or high treatments being intermediate.

Overall, increasing the ratios of Ile, Val, and Trp tended to increase ADG (Quadratic, $P = 0.084$) and ADFI (Linear, $P = 0.060$), and improve (Quadratic, $P = 0.087$) F/G, with the best performance observed from pigs fed the medium ratio treatment. For carcass characteristics, there was a tendency (Quadratic, $P = 0.080$) for reduced lean percent as the ratios of Ile, Val, and Trp increased, but no other impacts on carcass characteristics were observed.

Table 8 represents the comparison of the actual ADG of pigs fed these treatments to that predicted by Cemin (2019). After adjusting the intercept for the control pigs, we observed that the model overestimated the ADG for the Low ratio treatment in Phase 1 by 1.6%, but then underestimated the ADG in Phase 2, 3, and 4 by 5, 4, or 11%, respectively. The prediction equation overestimated the ADG in all phases for the High ratio treatment by 4.9, 2.2, 2.9, and 1% for Phases 1 to 4, respectively. The Medium ratio treatment had the overall best match to the prediction equation with Phase 1 ADG overestimated by 2.5%, but Phase 2, 3, and 4 underestimated by 1, 1, and 6%, respectively.

Discussion:

These trials confirmed that increasing Val, Ile, and Trp in DDGS diets containing low SBM and high Lys-HCl improved growth performance and final BW compared with pigs fed diets containing low SBM and high levels of Lys-HCl without added Val, Ile and Trp. The response to added Val on growth performance was greater in the grower period, whereas the response to added Ile on growth performance was greater in late finishing. Pigs fed the diet with added Trp did not respond as predicted by the model, which was unexpected. Recent research from the University of Illinois suggests that dietary valine may need to be increased in combination with dietary Trp for optimal performance in diets with high Leu:Lys ratios. Our research would support that conclusion. For the first trial, the model successfully predicted the ADG for the PC+Val and PC+Ile treatments in practical commercial finishing diets. Experiment 2 further demonstrated that increasing the inclusion of Val, Ile, and Trp in diets with low SBM and high Lys-HCl that contain high Leu will improve growth performance. The results demonstrated a quadratic response where increasing the ratios from low to medium levels improved performance, but additional benefits were not observed with high ratios of Ile, Val, and Trp. This data thus demonstrated that when diets contain a Leu:Lys ratio in the range of 140-155, Val:Lys, Ile:Lys, and Trp:Lys at 72, 60, and 21.0, respectively is sufficient to optimize performance. Collectively, these results demonstrate that the negative effects of high Leu in corn-DDGS-based diets that contain low SBM and high Lys-HCl can be overcome by increasing the ratios of Val, Ile, and Trp to Lys. These trials provide solutions to producers to take advantage of lower diet costs when feeding DDGS diets with low SBM and high Lys-HCl in order to maintain growth performance similar to a higher priced diet containing higher levels of SBM.

Table 1. Phase 1 and 2 diet composition (as-fed basis), Exp. 1[1,2]

	Phase 1						Phase 2					
Item	HSBM	NC	PC	PC+Val	PC+Ile	PC+Trp	HSBM	NC	PC	PC+Val	PC+Ile	PC+Trp
Ingredients, %												
Corn	41.92	55.53	50.94	50.87	50.89	50.92	47.00	60.35	56.03	55.91	55.92	56.01
Soybean meal (46.5% CP)	24.27	10.31	15.07	15.08	15.08	15.07	19.34	5.71	10.14	10.15	10.15	10.14
DDGS, > 6 and < 9% Oil	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Choice white grease	1.50	1.00	1.15	1.15	1.15	1.15	1.55	1.05	1.20	1.25	1.25	1.20
Calcium carbonate	1.25	1.20	1.22	1.22	1.22	1.22	1.19	1.14	1.15	1.15	1.15	1.15
Calcium phosphate	0.29	0.44	0.40	0.40	0.40	0.40	0.14	0.30	0.25	0.25	0.25	0.25
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
L-Lysine-HCl	0.15	0.58	0.43	0.43	0.43	0.43	0.16	0.58	0.44	0.44	0.44	0.44
DL-Methionine	-	0.08	0.05	0.05	0.05	0.05	-	0.05	0.04	0.04	0.04	0.04
L-Threonine	-	0.14	0.08	0.08	0.08	0.08	-	0.14	0.08	0.08	0.08	0.08
L-Tryptophan	-	0.05	0.04	0.04	0.04	0.06	-	0.05	0.05	0.05	0.05	0.07
L-Valine	-	0.06	-	0.07	-	-	-	0.03	-	0.07	-	-
L-Isoleucine	-	-	-	-	0.05	-	-	-	-	-	0.06	-
VTM[3]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Phytase[4]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Calculated analysis												
Standardized ileal digestible (SID) amino acids, %												
Lysine	0.98	0.98	0.98	0.98	0.98	0.98	0.87	0.87	0.87	0.87	0.87	0.87
Isoleucine:lysine	76	53	61	61	66	61	77	51	59	59	66	59
Leucine:lysine	168	133	145	145	145	145	175	137	150	150	150	150
Methionine:lysine	29	30	30	30	30	30	30	29	30	30	30	30
Methionine and cysteine:lysine	60	55	57	57	57	57	63	55	58	58	58	58
Threonine:lysine	67	62	62	62	62	62	68	62	62	62	62	62
Tryptophan:lysine	19.9	17.5	19.0	19.0	19.0	21.1	19.5	17.0	19.0	19.0	19.0	21.8

Valine:lysine	85	68	70	76	70	70	86	64	70	77	70	70
Lysine:net energy, g/Mcal	3.92	3.92	3.92	3.92	3.92	3.92	3.45	3.45	3.45	3.45	3.45	3.45
Crude protein, %	21.49	16.64	18.26	18.31	18.29	18.28	19.58	14.82	16.36	16.40	16.39	16.38
Net energy kcal/lb	1,134	1,134	1,134	1,134	1,134	1,134	1,145	1,145	1,145	1,145	1,145	1,145
Calcium, %	0.65	0.61	0.63	0.63	0.63	0.63	0.59	0.55	0.56	0.56	0.56	0.56
STTD P, %	0.39	0.39	0.39	0.39	0.39	0.39	0.35	0.35	0.35	0.35	0.35	0.35
Chemical analysis[5]												
Crude protein, %	21.44	16.52	18.00	18.38	17.78	18.42	20.34	15.48	17.38	17.94	17.08	16.83
Total calcium, %	0.67	0.76	0.86	0.76	0.60	0.86	0.69	0.82	0.83	0.70	0.78	0.95
Total phosphorus, %	0.60	0.61	0.60	0.57	0.56	0.57	0.59	0.56	0.55	0.57	0.58	0.65

[1]Phase 1 diets were fed from d 0 to 16 (74.0 to 111.5 lb) and phase 2 diets were fed from d 16 to 40 (111.5 to 164.7 lb).
[2]HSBM = high soybean meal. NC = negative control. PC = positive control. PC+Val = positive control + valine. PC+Ile = positive control + isoleucine. PC+Trp = positive control + tryptophan.
[3]Vitamin and mineral premix provided per kg of complete diet: 90 mg Zn, 37 mg Fe, 11 mg Mn, 15 mg Cu, 0.18 mg I, 0.30 mg of Se, 2507 IU vitamin A, 318 IU vitamin D,12 IU vitamin E, 0.01 mg vitamin B12, 11.6 mg niacin, 7.4 mg pantothenic acid, and 2.0 mg riboflavin.
[4]Smizyme TS G5 2,500 (Origination Inc., St. Paul, MN) provided 284 units of phytase FTU/lb of diet with an assumed release of 0.12 available P.
[5]A composite sample of each dietary treatment for each phase was collected, homogenized, and submitted to Agriculture Experiment Station Chemical Laboratories (University of Missouri-Columbia, MO) and analyzed.
STTD P = standardized total tract digestible phosphorus.

Table 2. Phase 3 and 4 diet composition (as-fed basis), Exp. 1[1,2]

	Phase 3						Phase 4					
Item	HSBM	NC	PC	PC+Val	PC+Ile	PC+Trp	HSBM	NC	PC	PC+Val	PC+Ile	PC+Trp
Ingredients, %												
Corn	51.34	62.55	60.58	60.46	60.45	60.55	62.44	71.87	70.00	69.87	69.88	69.92
Soybean meal (46.5% CP)	15.07	3.58	5.55	5.56	5.56	5.55	13.96	4.27	6.24	6.25	6.25	6.25
DDGS, > 6 and < 9% Oil	30.00	30.00	30.00	30.00	30.00	30.00	20.00	20.00	20.00	20.00	20.00	20.00
Choice white grease	1.50	1.10	1.20	1.25	1.25	1.20	1.45	1.10	1.15	1.20	1.20	1.20
Calcium carbonate	1.16	1.13	1.13	1.13	1.13	1.13	1.10	1.07	1.07	1.07	1.07	1.07
Calcium phosphate	0.15	0.33	0.30	0.30	0.30	0.30	0.30	0.44	0.40	0.40	0.40	0.40
Salt	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
L-Lysine-HCl	0.15	0.50	0.44	0.44	0.44	0.44	0.13	0.42	0.36	0.36	0.36	0.36
DL-Methionine	-	0.03	0.03	0.03	0.03	0.03	-	0.05	0.04	0.04	0.04	0.04
L-Threonine	-	0.11	0.10	0.10	0.10	0.10	-	0.11	0.09	0.09	0.09	0.09
L-Tryptophan	-	0.04	0.05	0.05	0.05	0.07	-	0.04	0.04	0.04	0.04	0.06
L-Valine	-	0.02	-	0.06	-	-	-	0.02	-	0.07	-	-
L-Isoleucine	-	-	-	-	0.08	-	-	-	-	-	0.07	-
VTM[3]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Phytase[4]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Calculated analysis												
Standardized ileal digestible (SID) amino acids, %												
Lysine	0.76	0.76	0.76	0.76	0.76	0.76	0.67	0.67	0.67	0.67	0.67	0.67
Isoleucine:lysine	78	53	58	58	67	58	77	53	58	58	68	58
Leucine:lysine	187	150	157	157	157	157	183	148	155	155	155	155
Methionine:lysine	32	29	30	30	30	30	32	32	32	32	32	32
Methionine and cysteine:lysine	67	58	59	59	59	59	67	61	62	61	61	62
Threonine:lysine	70	64	66	66	66	66	69	65	66	66	66	66

Tryptophan:lysine	19.3	17.0	19.0	19.0	19.0	22.2	19.7	17.5	19.0	19.0	19.0	23.1
Valine:lysine	90	68	70	78	70	70	88	68	70	80	70	70
Lysine:net energy, g/Mcal	3.00	3.00	3.00	3.00	3.00	3.00	2.61	2.61	2.61	2.61	2.61	2.61
Net energy, kcal/lb	1,151	1,151	1,151	1,151	1,151	1,151	1,165	1,165	1,165	1,165	1,165	1,165
Crude protein, %	17.91	13.87	14.57	14.61	14.62	14.59	15.53	12.16	12.84	12.88	12.88	12.86
Calcium, %	0.57	0.55	0.55	0.55	0.55	0.55	0.56	0.54	0.54	0.54	0.54	0.54
STTD P, %	0.34	0.35	0.35	0.35	0.35	0.35	0.34	0.34	0.34	0.34	0.34	0.34
Chemical analysis[5]												
Crude protein, %	18.64	14.34	14.62	14.06	14.80	14.97	14.98	13.55	13.23	12.91	13.61	13.10
Total calcium, %	0.63	0.66	0.63	0.71	0.75	0.53	0.79	0.64	0.54	0.58	0.77	0.73
Total phosphorus, %	0.54	0.52	0.58	0.55	0.54	0.51	0.46	0.50	0.42	0.43	0.50	0.47

[1]Phase 3 diets were fed from d 40 to 64 (164.7 to 217.1 lb) and phase 4 diets were fed from d 64 to 103 (217.1 to market, respectively).
[2]HSBM = high soybean meal. NC = negative control. PC = positive control. PC+Val = positive control + valine. PC+Ile = positive control + isoleucine. PC+Trp = positive control + tryptophan.
[3]Vitamin and mineral premix provided per kg of complete diet: 90 mg Zn, 37 mg Fe, 11 mg Mn, 15 mg Cu, 0.18 mg I, 0.30 mg of Se, 2507 IU vitamin A, 318 IU vitamin D,12 IU vitamin E, 0.01 mg vitamin B12, 11.6 mg niacin, 7.4 mg pantothenic acid, and 2.0 mg riboflavin.
[4]Smizyme TS G5 2,500 (Origination Inc., St. Paul, MN) provided 284 units of phytase FTU/lb of diet with an assumed release of 0.12 available P.
[5]A composite sample of each dietary treatment for each phase was collected, homogenized, and submitted to Agriculture Experiment Station Chemical Laboratories (University of Missouri-Columbia, MO) and analyzed.
STTD P = standardized total tract digestible phosphorus.

Table 3. Effects of supplemental Val, Ile, Trp on growth performance of growing-finishing pigs, Exp. 1[1,2]

Item[3]	HSBM	NC	PC	PC+Val	PC+Ile	PC+Trp	SEM	Probability, *P* =
Initial BW, lb	73.9	73.8	74.0	74.0	74.1	73.9	1.38	0.994
d 54 BW, lb	201.6[a]	194.3[c]	196.6[bc]	200.9[ab]	197.9[abc]	198.7[abc]	1.37	< 0.001
Final BW, lb	300.3[a]	287.9[b]	296.1[ab]	299.8[a]	298.5[a]	295.1[ab]	2.11	< 0.001
Grower (d 0 to 54)								
ADG, lb	2.38[a]	2.25[b]	2.29[ab]	2.37[a]	2.31[ab]	2.31[ab]	0.024	< 0.001
ADFI, lb	5.10	4.99	5.05	5.16	5.07	5.08	0.045	0.175
F/G	2.15[b]	2.22[a]	2.21[a]	2.18[ab]	2.19[ab]	2.20[ab]	0.018	0.007
Finisher (d 54 to 103)								
ADG, lb	2.17[ab]	2.11[b]	2.17[ab]	2.16[ab]	2.22[a]	2.13[ab]	0.027	0.080
ADFI, lb	6.66[ab]	6.47[b]	6.64[ab]	6.72[a]	6.69[ab]	6.56[ab]	0.065	0.042
F/G	3.08[ab]	3.07[ab]	3.06[ab]	3.12[a]	3.02[b]	3.08[ab]	0.021	0.051
Overall (d 0 to 103)								
ADG, lb	2.28[a]	2.18[b]	2.24[ab]	2.27[a]	2.27[a]	2.23[ab]	0.019	< 0.001
ADFI, lb	5.80[ab]	5.65[b]	5.76[ab]	5.87[a]	5.80[ab]	5.73[ab]	0.046	0.027
F/G	2.54	2.58	2.57	2.58	2.55	2.58	0.014	0.060
Carcass characteristics								
HCW, lb	219.7[a]	210.5[b]	218.3[a]	219.7[a]	218.6[a]	217.1[ab]	1.96	0.004
Carcass yield, %	73.2	73.4	73.4	73.4	73.3	73.7	0.298	0.931
Backfat depth, in[4]	0.59	0.61	0.60	0.62	0.60	0.61	0.011	0.335
Loin depth, in[4]	2.58	2.53	2.56	2.54	2.56	2.56	0.016	0.136
Lean, %[4]	54.9	54.5	54.8	54.5	54.7	54.7	0.14	0.190
Economics, $/pig placed								
Feed cost[5]	57.41[a]	53.00[c]	54.77[b]	56.11[ab]	57.03[a]	54.98[b]	0.467	< 0.001
Feed cost/lb gain[5,6]	0.243[a]	0.235[c]	0.237[c]	0.239[bc]	0.243[ab]	0.239[bc]	0.0013	< 0.001
Revenue[7]	104.61[a]	99.13[b]	102.80[ab]	104.27[a]	103.62[ab]	101.51[ab]	1.210	0.017
IOFC[8]	47.20	46.13	48.03	48.16	46.60	46.54	0.982	0.587

[1]A total of 1,200 pigs in two groups were used in a 103-d study with 20 pigs per pen and 10 replicates per treatment.
[2]HSBM = high soybean meal. NC = negative control. PC = positive control. PC+Val = positive control + valine. PC+Ile = positive control + isoleucine. PC+Trp = positive control + tryptophan.
[3] BW = body weight. ADG = average daily gain. ADFI = average daily feed intake. F/G = feed-to-gain ratio. HCW = hot carcass weight.
[4]Adjusted using HCW as covariate.
[5]Ingredient prices at the time of the study were: corn ($0.070/lb), SBM ($0.151/lb), DDGS ($0.073/lb), L-Lys ($0.681/lb), L-Trp ($2.564/lb), L-Ile ($1.200/lb), L-Val ($4.764/lb).
[6]Feed cost/lb gain = total feed cost per pen divided by total gain per pen.
[7]Revenue = total pen gain × yield × $0.65.
[8]Income over feed cost = revenue - feed cost.
[a,b,c]Means with different superscripts are significantly different ($P \leq 0.05$).

Table 4. Comparison of predicted ADG based on the model versus the actual ADG, Exp. 1[1,2]

Item[3]	HSBM	NC	PC	PC+Val	PC+Ile	PC+Trp
Grower						
Predicted ADG, lb	2.38	2.26	2.34	2.38	2.37	2.38
Actual ADG, lb	2.38	2.25	2.29	2.37	2.31	2.31
Actual vs predicted, %[4]	100%	99.4%	97.8%	99.5%	97.4%	96.9%
Finisher						
Predicted ADG, lb	2.17	2.05	2.12	2.17	2.16	2.17
Actual ADG, lb	2.17	2.11	2.17	2.16	2.22	2.13
Actual vs predicted, %[4]	100%	102.7%	102.5%	99.6%	103.0%	98.4%
Overall						
Predicted ADG, lb	2.28	2.18	2.24	2.28	2.28	2.28
Actual ADG, lb	2.28	2.18	2.24	2.27	2.27	2.23
Actual vs predicted, %[4]	100.0	100.0	100.0	99.6	99.6	97.8

[1]Prediction equation used was derived by Cemin, H. S., M. D. Tokach, S. S. Dritz, J. C. Woodworth, J. M. DeRouchey, R. D. Goodband, 2019, Meta-regression analysis to predict the influence of branched-chain and large neutral amino acids on growth performance of pigs. J. Anim. Sci. 97:2505-2514. doi: 10.1093/jas/skz118., the intercept term was adjusted until the predicted ADG matched the actual ADG of HSBM treatment. The adjusted intercept term equation was then used to predict the ADG of the remaining treatments.

[2]HSBM = high soybean meal. NC = negative control. PC = positive control. PC+Val = positive control + valine. PC+Ile = positive control + isoleucine. PC+Trp = positive control + tryptophan.

[3]ADG = average daily gain.

[4]Actual vs. predicted = actual ADG/predicted ADG.

Table 5. Phase 1 and 2 diet composition (as-fed basis), Exp. 2[1]

	Phase 1				Phase 2			
Item	Control	Low ratio	Medium ratio	High ratio	Control	Low ratio	Medium ratio	High ratio
Ingredients, %								
Corn	44.20	57.35	57.15	56.90	49.95	61.35	61.15	60.90
Soybean meal	22.85	8.55	8.60	8.60	17.30	4.95	4.95	4.95
DDGS, > 6 and < 9% oil	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Choice white grease	0.80	1.00	1.08	1.15	0.78	0.95	1.00	1.10
Calcium carbonate	1.10	1.13	1.13	1.13	1.05	1.08	1.08	1.08
Calcium phosphate	0.28	0.44	0.44	0.44	0.15	0.30	0.30	0.30
Sodium Chloride	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
L-Lys-HCl	0.11	0.55	0.55	0.55	0.14	0.52	0.52	0.52
DL-Met	---	0.08	0.08	0.08	---	0.05	0.05	0.05
L-Thr	---	0.19	0.19	0.19	---	0.16	0.16	0.16
L-Trp	0.02	0.05	0.08	0.10	0.02	0.05	0.08	0.09
L-Val	---	0.01	0.06	0.14	---	---	0.04	0.12
L-Ile	---	---	0.05	0.10	---	---	0.05	0.09
VTM[2]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Phytase[3]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

Continued

Table 5. Phase 1 and 2 diet composition (as-fed basis), Exp. 2[1]

	Phase 1				Phase 2			
Item	Control	Low ratio	Medium ratio	High ratio	Control	Low ratio	Medium ratio	High ratio
Calculated analysis								
Standardized ileal digestible amino acids, %								
Lysine	0.98	0.98	0.98	0.98	0.87	0.87	0.87	0.87
Isoleucine:lysine	82	55	60	65	81	55	60	65
Leucine:lysine	177	139	139	139	183	147	147	147
Methionine:lysine	30	32	32	32	32	31	31	31
Methionine and cysteine:lysine	61	57	57	57	64	57	57	57
Threonine:lysine	65	65	65	65	65	65	65	65
Tryptophan:lysine	23.0	18.0	21.0	23.0	23.0	18.0	21.0	23.0
Valine:lysine	92	67	72	80	92	67	72	80
Lysine:net energy, g/Mcal	3.86	3.86	3.86	3.86	3.41	3.41	3.41	3.41
Crude protein, %	21.8	16.7	16.8	16.9	19.7	15.3	15.3	15.4
Net energy kcal/lb	1,152	1,152	1,152	1,152	1,156	1,156	1,156	1,156
Calcium, %	0.60	0.60	0.60	0.60	0.54	0.54	0.54	0.54
STTD P, %	0.41	0.41	0.41	0.41	0.37	0.37	0.37	0.37

[1]Phase 1 were fed from approximately 90 to 120 lb and phase 2 were fed from approximately 120 to 160 lb.

[2]Vitamin and mineral premix provided per kg of complete diet: 90 mg Zn, 37 mg Fe, 11 mg Mn, 15 mg Cu, 0.18 mg I, 0.30 mg of Se, 2507 IU vitamin A, 318 IU vitamin D, 12 IU vitamin E, 0.11 mg vitamin B12, 11.3 mg of niacin, 7.4 mg pantothenic acid, and 2.0 mg riboflavin.

[3]Quantum Blue 10p (AB Vista, Marlborough, Wiltshire) provided 626 units of phytase FTU/kg of diet with assumed release of 0.16 available P.

STTD P = standardized total tract digestible phosphorus.

Table 6. Phase 3 and 4 diet composition (as-fed basis), Exp. 2[1]

Item	Phase 3 Control	Phase 3 Low ratio	Phase 3 Medium ratio	Phase 3 High ratio	Phase 4 Control	Phase 4 Low ratio	Phase 4 Medium ratio	Phase 4 High ratio
Ingredients, %								
Corn	55.75	66.05	65.85	65.70	62.90	73.25	73.10	72.95
Soybean meal	11.60	0.50	0.55	0.55	14.40	3.20	3.20	3.25
DDGS, > 6 and < 9% oil	30.00	30.00	30.00	30.00	20.00	20.00	20.00	20.00
Choice white grease	0.88	0.98	1.05	1.10	0.80	0.95	1.00	1.03
Calcium carbonate	0.98	1.08	1.08	1.08	0.95	0.98	0.98	0.98
Calcium phosphate	---	---	---	---	---	0.15	0.15	0.15
Sodium Chloride	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
L-Lys-Hcl	0.18	0.52	0.52	0.52	0.08	4.20	4.20	4.20
DL-Met	---	0.03	0.03	0.03	---	0.03	0.03	0.03
L-Thr	---	0.14	0.14	0.14	---	0.15	0.15	0.15
L-Trp	0.03	0.05	0.08	0.09	0.02	0.04	0.06	0.08
L-Val	---	---	0.04	0.10	---	---	0.03	0.09
L-Ile	---	0.02	0.06	0.10	---	0.01	0.04	0.08
VTM[2]	0.10	0.10	0.10	0.10	0.31	0.31	0.31	0.31
Phytase[3]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

Continued

Table 6. Phase 3 and 4 diet composition (as-fed basis), Exp. 2

Item	Phase 3				Phase 4			
	Control	Low ratio	Medium ratio	High ratio	Control	Low ratio	Medium ratio	High ratio
Calculated analysis								
Standardized ileal digestible amino acids, %								
Lysine	0.76	0.76	0.76	0.76	0.70	0.70	0.70	0.70
Isoleucine:lysine	79	55	60	65	83	55	59	65
Leucine:lysine	191	154	154	154	189	148	148	148
Methionine:lysine	33	30	30	30	33	31	31	31
Methionine and cysteine:lysine	67	58	58	58	67	58	58	58
Threonine:lysine	65	65	65	65	67	67	67	67
Tryptophan:lysine	23.0	18.0	21.0	23.0	23.0	18.0	21.0	23.0
Valine:lysine	93	67	72	80	95	67	72	80
Lysine:net energy, g/Mcal	2.96	2.96	2.96	2.96	2.71	2.71	2.71	2.71
Crude protein, %	17.5	13.5	13.6	13.7	16.2	12.2	12.2	12.3
Net energy kcal/lb	1,163	1,163	1,163	1,163	1,172	1,172	1,172	1,172
Calcium, %	0.47	0.47	0.47	0.47	0.51	0.51	0.51	0.51
STTD P, %	0.33	0.30	0.30	0.30	0.30	0.30	0.30	0.30

[1]Phase 3 was fed from approximately 160 to 220 lb and phase 4 was fed from approximately 220 to 285 lb.

[2]For phase 3 vitamin and mineral premix provided per kg of complete diet: 90 mg Zn, 37 mg Fe, 11 mg Mn, 15 mg Cu, 0.18 mg I, 0.30 mg of Se, 2507 IU vitamin A, 318 IU vitamin D, 12 IU vitamin E, 0.01 mg vitamin B12, 11.6 mg niacin, 7.4 mg pantothenic acid, and 2.0 mg riboflavin. For phase 4 vitamin and trace mineral premix provided per kg of complete diet: 73 g Zn, 73 g Fe, 22 g Mn, 11 g Cu, 0.2 g I, 0.2 g Se, 3,527,399 IU vitamin A, 881,850 IU vitamin D, 17,637 IU vitamin E, 1,764 mg vitamin K, 15.4 mg vitamin B12, 33,069 mg niacin, 11,023 mg pantothenic acid, 3,307 mg riboflavin.

[3]Quantum Blue 10p (AB Vista, Marlborough, Wiltshire) provided 626 units of phytase FTU/kg of diet with assumed release of 0.16 available P.

Table 7. Effect of branch chain amino acid ratios on growth performance of growing pigs, Exp. 2[1]

	Control	Low ratio	Medium ratio	High ratio			
Soybean meal	High	Low	Low	Low			
Ile:lys	>79	55	60	65			
Val:lys	>92	67	72	80			
Trp:lys	23.0	18.0	21.0	23.0			
						P =[2]	
Item[3]					SEM	Linear	Quadratic
Starting BW, lb	90.8	90.8	90.9	90.8	1.02	0.673	0.488
Ending BW, lb	302.5	298.6	301.8	299.9	1.83	0.480	0.104
Phase 1[4]							
ADG, lb	1.98[a]	1.84[b]	1.93[a]	1.95[a]	0.030	0.001	0.150
ADFI, lb	4.26	4.25	4.26	4.38	0.050	0.034	0.407
F/G	2.16[c]	2.33[a]	2.22[bc]	2.24[b]	0.028	0.008	0.006
Phase 2[5]							
ADG, lb	2.25	2.22	2.24	2.25	0.019	0.225	0.564
ADFI, lb	5.80	5.67	5.75	5.80	0.061	0.030	0.821
F/G	2.58	2.56	2.56	2.58	0.019	0.224	0.596
Phase 3[6]							
ADG, lb	2.07[a]	1.99[b]	2.04[ab]	2.04[ab]	0.018	0.462	0.350
ADFI, lb	6.31	6.24	6.26	6.34	0.064	0.605	0.674
F/G	3.05	3.13	3.08	3.12	0.032	0.360	0.182
Phase 4[7]							
ADG, lb	2.05[b]	2.15[a]	2.15[a]	2.09[ab]	0.043	0.115	0.538
ADFI, lb	6.90	6.86	6.97	6.90	0.080	0.710	0.196
F/G	3.39[a]	3.21[b]	3.27[ab]	3.32[ab]	0.051	0.070	0.833
Overall							
ADG, lb	2.09	2.05	2.09	2.08	0.015	0.062	0.084
ADFI, lb	5.79	5.72	5.78	5.82	0.042	0.060	0.877
F/G	2.77	2.79	2.77	2.80	0.020	0.612	0.087
Carcass Characteristics							
HCW, lb	222.8	218.6	220.6	221.5	2.015	0.259	0.760
Yield, %	73.8	74.3	74.1	73.9	0.366	0.496	0.925
Lean, %	55.6	55.6	55.5	55.2	0.166	0.080	0.602
Back fat, in	0.54	0.55	0.55	0.57	0.012	0.198	0.609
Loin depth, in	2.67	2.65	2.64	2.61	0.021	0.117	0.947

[a,b,c]Means within a row with different superscript differ ($P < 0.05$) using the Tukey-Kramar adjustment.

[1]A total of 1,916 pigs were used in a study split between 2 barns at New Fashion Pork, Jackson, MN with approximately 20 pigs per pen and 25 replications per treatment. A total of 322 pigs from barn 2 were used for carcass data analysis.
[2]Linear and quadratic was measured based on the sum of Ile:lys, Val:lys, and Trp:lys as a ratio to Leu:lys within each phase.
[3]ADG = average daily gain. ADFI = average daily feed intake. F/G = feed to gain ratio.
[4]Phase 1 was fed from d 0 to 15 in barn 2 and d 0 to 28 in barn 1.
[5]Phase 2 was fed from d 15 to 43 in barn 2 and d 28 to 56 in barn 1.
[6]Phase 3 was fed from d 43 to 77 in barn 2 and d 56 to 84 in barn 1.
[7]Phase 4 was fed from d 71 to 106 in barn 2 and d 84 to 107 in barn 1.

Table 8. Comparison of predicted ADG based on model versus the actual ADG, Exp. 2[1]

Item[2,3]	Control	Low ratio	Medium ratio	High ratio
Phase 1				
Predicted ADG, lb	1.98	1.87	1.98	2.05
Actual ADG, lb	1.98	1.84	1.93	1.95
Actual vs. predicted, %[4]	100%	98.4%	97.5%	95.1%
Phase 2				
Predicted ADG, lb	2.25	2.11	2.22	2.30
Actual ADG, lb	2.25	2.22	2.24	2.25
Actual vs. predicted, %	100%	105%	101%	97.8%
Phase 3				
Predicted ADG, lb	2.07	1.91	2.02	2.10
Actual ADG, lb	2.07	1.99	2.04	2.04
Actual vs. predicted, %	100%	104%	101%	97.1%
Phase 4				
Predicted ADG, lb	2.05	1.93	2.03	2.12
Actual ADG, lb	2.05	2.15	2.15	2.09
Actual vs. predicted, %	100%	111%	106%	99%

[1]Prediction equation used was derived by Cemin 2019 (Cemin, H. S., M. D. Tokach, S.S. Dritz, J. C. Woodworth, J. M. DeRouchey, R.D. Goodband, 2019, Meta-regression analysis to predict the influence of branched-chain and large neutral amino acids on growth performance of pigs. J. Anim. Sci. 97:2505-2514. doi:10.1093/jas/skz118.), the intercept term was adjusted until the predicted ADG matched the actual ADG of the control treatment. The adjusted intercept term equation was then used to predict the ADG of the remaining treatments.

[3]ADG = average daily gain.

[4]Actual vs. predicted = actual ADG/predicted ADG.