Kansas Agricultural Experiment Station Research Reports

Volume 6
Issue 10 *Swine Day*

Article 18

2020

Improving Performance of Finishing Pigs with Added Valine, Isoleucine, and Tryptophan: Validating a Meta-Analysis Model

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Recommended Citation

Kerkaert, H. R.; Cemin, H. S.; Woodworth, J. C.; DeRouchey, J. M.; Dritz, S. S.; Tokach, M. D.; Goodband, R. D.; Haydon, K. D.; Hastad, C.; and Post, Z. (2020) "Improving Performance of Finishing Pigs with Added Valine, Isoleucine, and Tryptophan: Validating a Meta-Analysis Model," *Kansas Agricultural Experiment Station Research Reports*: Vol. 6: Iss. 10. https://doi.org/10.4148/2378-5977.7999

Improving Performance of Finishing Pigs with Added Valine, Isoleucine, and Tryptophan: Validating a Meta-Analysis Model

Abstract

Based on a recent meta-analysis, we hypothesized that increased dietary Val, Ile, or Trp could correct possible amino acid interactions caused by high dietary Leu in diets containing high levels of corn protein, namely dried distillers grains with solubles (DDGS). A total of 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 NRC4 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 pigs were fed diets with 20% DDGS until market. Data were analyzed as a randomized complete block design using the lmer function in the lme4 package in R with pen considered as the experimental unit, body weight, and pen location as a blocking factor, and treatment as a fixed effect with 10 replicates/treatment.

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. In conclusion, increasing Val or Ile in high Lys-HCl-DDGS-based diets improved growth performance and final BW compared with pigs fed diets containing high levels of Lys-HCl without added Val and Ile. These results demonstrate that the negative effects of high Leu concentrations in corn-DDGS-based diets can be corrected by increasing the ratios of Val and Ile to Lys.

Keywords

branch chain amino acids, isoleucine, lysine, swine tryptophan, valine

Authors

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Improving Performance of Finishing Pigs with Added Valine, Isoleucine, and Tryptophan: Validating a Meta-Analysis Model

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Summary

Based on a recent meta-analysis, we hypothesized that increased dietary Val, Ile, or Trp could correct possible amino acid interactions caused by high dietary Leu in diets containing high levels of corn protein, namely dried distillers grains with solubles (DDGS). A total of 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[4] 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 pigs were fed diets with 20% DDGS until market. Data were analyzed as a randomized complete block design using the lmer function in the lme4 package in R with pen considered as the experimental unit, body weight, and pen location as a blocking factor, and treatment as a fixed effect with 10 replicates/treatment.

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

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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. In conclusion, increasing Val or Ile in high Lys-HCl-DDGS-based diets improved growth performance and final BW compared with pigs fed diets containing high levels of Lys-HCl without added Val and Ile. These results demonstrate that the negative effects of high Leu concentrations in corn-DDGS-based diets can be corrected by increasing the ratios of Val and Ile to Lys.

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,[4] 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[5] 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. Therefore, the objective of this study was to validate the growth performance predictions of a model which suggests that increased concentrations of Val, Ile, or Trp can ameliorate the poor performance of pigs fed diets containing high Leu.

Procedures

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. 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).

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[4] National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298.

[5] 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.

Approximately 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 fed in four phases and consisted of:

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; and
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 (Tables 1 and 2) 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 $P \leq 0.05$.

Results and Discussion

There were no notable differences revealed between the chemical and calculated analysis of the complete diets (Tables 1 and 2). The analyzed level of CP, Ca, and P followed the targeted dietary levels.

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.

In conclusion, increasing Val or Ile in high Lys-HCl-DDGS-based diets improved growth performance and final BW compared with pigs fed diets containing high levels of Lys-HCl without added Val and Ile. 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. Overall, the model successfully predicted the ADG for the PC+Val and PC+Ile treatments in practical commercial finishing diets. These results demonstrate that the negative effects of high Leu in corn-DDGS-based diets can be overcome by increasing the ratios of Val and Ile to Lys.

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

continued

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

Item	Phase 1						Phase 2					
	HSBM	NC	PC	PC+Val	PC+Ile	PC+Trp	HSBM	NC	PC	PC+Val	PC+Ile	PC+Trp
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)[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

continued

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