Journal of Animal Science, 2019, 4227–4234

doi:10.1093/jas/skz275
Advance Access publication August 17, 2019
Received: 22 May 2019 and **Accepted:** 14 August 2019
Non Ruminant Nutrition

NON RUMINANT NUTRITION

Bioavailability of valine in spray-dried L-valine biomass is not different from that in crystalline L-valine when fed to weanling pigs[1]

Maryane S. F. Oliveira,[†] John K. Htoo,[‡] J. Caroline González-Vega,[‡] and Hans H. Stein[†,‖,2]

[†]Department of Animal Sciences, University of Illinois at Urbana – Champaign, Urbana, IL 61801, [‡]Evonik Nutrition & Care GmbH, Hanau-Wolfgang, Germany, and [‖]Division of Nutritional Sciences, University of Illinois, Urbana, IL 61801

[1]Funding provided by Evonik Nutrition & Care GmbH, Hanau-Wolfgang, Germany is appreciated.

[2]Corresponding author: hstein@illinois.edu

Abstract

An experiment was conducted to test the hypothesis that Val from a spray dried L-Val fermentation biomass (Val-FB; 64.4% L-Val) has a bioavailability of 100% relative to Val from L-Val (98% L-Val) when fed to weanling pigs. A Val-deficient basal diet containing 0.63% standardized ileal digestible (**SID**) Val was formulated. Six additional diets were prepared by supplementing the basal diet with 0.08%, 0.17%, or 0.25% L-Val or 0.12%, 0.25%, or 0.37% Val-FB to create experimental diets from both Val sources that contained 0.71%, 0.79%, or 0.87% SID Val. Two hundred twenty-four weaned pigs (6.87 ± 0.64 kg initial BW) were allotted to a randomized complete block design with 7 diets, 4 pigs per pen, and 8 replicate pens per diet. Diets were fed for 20 d. At the conclusion of the experiment, a blood sample from 1 pig per pen was analyzed for blood urea nitrogen (**BUN**) and plasma free AA. A linear regression model was used to estimate the relative bioavailability (**RBV**) of Val in Val-FB relative to Val from L-Val. Results indicated that the final BW and ADG were greater ($P < 0.01$) for pigs fed diets supplemented with Val-FB than pigs fed diets supplemented with L-Val. The ADFI decreased (linear, $P \leq 0.01$), whereas G:F increased (linear, $P < 0.01$) by increasing inclusion of both Val sources in the diets. Regardless of source of dietary Val, BUN values were reduced (linear and quadratic, $P < 0.01$) as the concentration of Val in the diet increased. Pigs fed diets supplemented with L-Val had increased (linear and quadratic, $P \leq 0.05$) concentrations of Val and Arg in plasma, and plasma concentrations of Ile, Leu, Lys, Ala, Cys, and Pro linearly increased ($P < 0.05$). There was also an increase (linear, $P < 0.05$) in plasma concentrations of Ile, Leu, Met, Ala, Asp, Cys, and Pro as Val-FB was added to the diets, and the concentration of Val in plasma increased (linear and quadratic, $P < 0.05$). Using L-Val as the standard, the RBV of Val in Val-FB as determined by ADG, G:F, and final BW was 146%, 135%, and 143%, respectively, with 95% confidence intervals of 99% to 191%, 83% to 187%, and 70% to 217%, respectively. In conclusion, the linear regression estimated a RBV of at least 100% for Val in Val-FB relative to Val from L-Val, and pigs fed diet supplemented with Val-FB had greater final BW, ADG, and G:F than pigs fed diets supplemented with the same amount of Val from L-Val.

Key words: bioavailability, fermentation biomass, growth performance, pigs, valine

Introduction

Increased availability of crystalline amino acids (AA) allows for a reduction in the concentration of CP in diets for pigs. Low-CP diets that are adequately fortified with crystalline AA maintain optimal performance and protein deposition (Lordelo et al., 2008). With advances in fermentation technology, the cost of crystalline Val is now at a level that is often competitive in diets for weanling pigs and it is believed that the ratio between standardized ileal digestible (**SID**) Val and SID Lys that maximizes growth performance is close to 70% (Barea et al., 2009; NRC, 2012; Rostagno et al., 2017).

Feed-grade L-Val (98% purity) is currently available for the feed industry and is the primary source of supplemental Val in commercial diet for pigs. In the production of L-Val, valine-producing bacteria are incubated with carbohydrates and nitrogen in fermentation facilities, and conventional crystalline L-Val is produced by harvesting L-Val from the fermentation biomass at the conclusion of the fermentation period. An alternative source of feed grade L-Val may be obtained by spray drying the entire biomass from the L-Val production because this biomass contains approximately 64.5% L-Val. However, the relative bioavailability (**RBV**) by weanling pigs of Val in Val fermentation biomass (**Val-FB**) has not been reported. Therefore, the objective of this experiment was to test the hypothesis that the RBV of Val in Val-FB fed to weanling pigs is at least 100% if Val in crystalline L-Val is used as the standard.

Material and Methods

The protocol for the experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois at Urbana – Champaign. Two sources of Val were used. Both sources were provided by Evonik Nutrition & Care GmbH (Hanau, Germany) and the 2 sources included crystalline feed-grade L-Val with 98% purity and Val-FB with a concentration of 64.6% L-Val. Both sources of Val were produced via fermentation using a strain of *Corynebacterium glutamicum* that has been engineered for improved efficiency of Val synthesis. The difference between the 2 sources of Val is that L-Val is extracted from the fermentation biomass for producing the standard crystalline L-Val, whereas Val-FB is produced by a direct spray granulation of the fermentation broth with biomass, which in addition to Val, also contains small quantities of other AA and some residual carbohydrates. The final dried product is in granular form.

Seven diets were formulated. Diets were based on corn, distillers dried grains with solubles (**DDGS**), corn gluten meal, lactose, and soybean meal (Table 1), and all diets were formulated to contain 1.42% SID Lys. A Val-deficient basal diet was formulated (0.63% SID Val; 44% SID Val:Lys ratio), which is below the estimated requirement of 0.86% SID Val (NRC, 2012). However, the diet was formulated to be adequate in all other AA as suggested by NRC (2012). Three diets were formulated by adding 0.08%, 0.17%, or 0.25% L-Val to the basal diet to provide 0.71%, 0.79%, or 0.87% SID Val (50%, 56%, and 61% SID Val:Lys ratios, respectively) in these diets. Three additional diets were formulated by adding 0.12%, 0.25%, or 0.37% Val-FB to the basal diet to increase the quantity of SID Val to 0.71%, 0.79%, and 0.87%, respectively, which also corresponded to 50%, 56%, and 61% SID Val:Lys ratios, respectively (Tables 2 and 3).

Diets and ingredients were analyzed for DM (method 930.15; AOAC Int., 2007), CP (method 990.0; AOAC Int., 2007), and for AA by ion-exchange chromatography with postcolumn derivatization with ninhydrin (Llames and Fontaine, 1994; Almeida et al., 2014a). Diets and ingredients were also analyzed for GE using an isoperibol bomb calorimeter (Model 6400, Parr Instruments, Moline, IL). All diets were formulated on the basis

Table 1. Analyzed composition of ingredients (as-fed basis)[1]

Analyzed composition, %	Corn	Soybean meal	Corn gluten meal	DDGS[2]	Val-FB[2]
DM, %	85.79	88.86	91.58	89.44	96.90
CP, %	6.84	47.53	63.99	29.27	67.50
GE, kcal/kg	3,779	4,217	5,069	4,365	5,053
Indispensable AA, %					
Arg	0.29	3.44	1.92	1.26	0.59
His	0.20	1.22	1.25	0.79	0.35
Ile	0.24	2.18	2.56	1.07	0.60
Leu	0.84	3.66	10.64	3.32	0.87
Lys	0.20	2.92	1.10	0.82	1.01
Met	0.15	0.64	1.60	0.58	0.48
Phe	0.34	2.43	4.04	1.40	0.84
Thr	0.25	1.86	2.11	1.08	0.47
Trp	0.05	0.65	0.31	0.21	0.07
Val	0.33	2.27	2.90	1.40	64.6
Dispensable AA, %					
Ala	0.51	2.05	5.60	2.07	3.47
Asp	0.45	5.42	3.75	1.87	1.10
Cys	0.15	0.65	1.15	1.12	0.08
Glu	1.24	8.61	13.95	4.86	1.94
Gly	0.27	2.00	1.81	1.14	0.80
Pro	0.58	2.34	5.99	2.36	0.56
Ser	0.33	2.38	3.27	1.369	0.39

[1]Dry matter, GE, and CP in corn, soybean meal, corn gluten meal, and DDGS were analyzed at the University of Illinois, Urbana. All other values were analyzed by Evonik Nutrition and Care GmbH (Hanau-Wolfgang, Germany).

[2]DDGS = distillers dried grains with solubles; Val-FB= Val-containing fermentation biomass product.

Table 2. Ingredient composition of experimental diets, as-fed basis

Item	Basal	L-Val			Val-FB		
Supplemental Val, %	0.00	0.08	0.16	0.24	0.08	0.16	0.24
Ground corn	65.51	65.51	65.51	65.51	65.51	65.51	65.51
Distillers dried grains with solubles	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Corn gluten meal	9.96	9.96	9.96	9.96	9.96	9.96	9.96
Milk lactose	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Soybean meal, 47.5% CP	2.99	2.99	2.99	2.99	2.99	2.99	2.99
Monocalcium phosphate	1.71	1.71	1.71	1.71	1.71	1.71	1.71
Limestone	1.41	1.41	1.41	1.41	1.41	1.41	1.41
Salt	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin-mineral premix[1]	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Biolys (54.6% Lys)	1.96	1.96	1.96	1.96	1.96	1.96	1.96
DL- Methionine (99%)	0.30	0.30	0.30	0.30	0.30	0.30	0.30
L-Threonine (98%)	0.43	0.43	0.43	0.43	0.43	0.43	0.43
L-Tryptophan (99%)	0.23	0.23	0.23	0.23	0.23	0.23	0.23
L-Isoleucine (99%)	0.27	0.27	0.27	0.27	0.27	0.27	0.27
L-Histidine (99%)	0.13	0.13	0.13	0.13	0.13	0.13	0.13
L-Val (98%)	–	0.08	0.17	0.25	–	–	–
Val-FB (64.6% L-Val)	–	–	–	–	0.12	0.25	0.37
Corn starch	0.40	0.32	0.23	0.15	0.28	0.15	0.03
Total, %	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[1]The vitamin-micromineral premix provided the following quantities of vitamins and micro minerals per kg of complete diet: vitamin A as retinyl acetate, 11,136 IU; vitamin D_3 as cholecalciferol, 2,208 IU; vitamin E as $_{DL-}$alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 0.24 mg; vitamin B_{12}, 0.03 mg; $_{D-}$pantothenic acid as $_{D-}$calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

Table 3. Analyzed composition of experimental diets, as-fed basis[1]

Item	Basal	L-Val			Val-FB[2]		
Supplemental Val, %	0.00	0.08	0.16	0.24	0.08	0.16	0.24
DM, %	89.31	89.36	89.38	89.45	89.34	89.44	89.46
CP, %	17.60	17.78	18.06	17.92	17.87	17.40	18.52
GE, kcal/kg	3,865	3,887	3,875	3,898	3,827	3,906	3,837
Indispensable AA, %							
Arg	0.67	0.67	0.66	0.69	0.70	0.67	0.70
His	0.50	0.49	0.50	0.51	0.51	0.46	0.50
Ile	0.79	0.81	0.82	0.83	0.83	0.82	0.84
Leu	1.87	1.87	1.88	1.98	1.95	1.81	1.96
Lys	1.50	1.55	1.34	1.46	1.52	1.35	1.49
Met	0.60	0.60	0.65	0.65	0.62	0.65	0.65
Phe	0.82	0.81	0.82	0.86	0.85	0.79	0.87
Thr	0.95	0.98	0.95	0.96	0.97	0.95	0.92
Trp	0.32	0.33	0.34	0.32	0.32	0.38	0.34
Val	0.70	0.79	0.88	0.98	0.80	0.85	0.96
Dispensable AA, %							
Ala	1.09	1.10	1.10	1.15	1.14	1.08	1.16
Asp	1.07	1.08	1.07	1.13	1.12	1.06	1.14
Cys	0.26	0.27	0.26	0.28	0.27	0.26	0.27
Glu	2.84	2.85	2.85	2.99	2.97	2.77	2.99
Gly	0.53	0.54	0.53	0.55	0.55	0.53	0.56
Pro	1.09	1.14	1.10	1.13	1.18	1.08	1.17
Ser	0.74	0.73	0.74	0.77	0.76	0.72	0.78

[1]Dry matter, GE, and CP were analyzed at the University of Illinois, Urbana, but all AA were analyzed by Evonik Nutrition and Care GmbH (Hanau-Wolfgang, Germany).
[2]Val-FB = Val-containing fermentation biomass product.

of NE and analyzed AA concentrations in the ingredients and the average SID of AA in ingredients (AMINODat® 5.0. Platinum version, 2016). All experimental diets were fed to pigs for 20 d.

A total of 224 weanling pigs that were the offspring of PIC line 359 boars mated to Camborough females (Pig Improvement Company, Hendersonville, TN) were used. On day 7 postweaning,

when pigs had an initial BW of 6.87 ± 0.64 kg, they were allotted to a randomized complete block design with BW as the blocking factor. There were 7 diets and 8 replicate pens per diet for a total of 56 pens. Four pigs (2 males and 2 females) were housed in each pen. Individual pig weights were recorded at the beginning (day 0) and at the conclusion (day 21) of the experiment and daily feed allotments were also recorded. The quantities of feed left in the feeders were recorded at the conclusion of the experiment and data for average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) for each diet were calculated based on the recorded pig weights and data for feed disappearance. On the last day of the experiment, a blood sample from one barrow in each pen was collected from the jugular vein in heparin-containing tubes. Blood samples were centrifuged at 1,500 × *g* at 4 °C for 15 min and 2 mL of plasma were transferred to 2-mL tubes and lyophilized. Serum samples were assayed for blood urea nitrogen (**BUN**) using a Beckman Coulter Clinical Chemistry AU analyzer (Beckman Coulter, Inc., Brea, CA). Concentrations of plasma free AA in blood plasma were determined by ion exchange chromatography using a Biochrom 20 amino acid analyzer lithium column and lithium buffers.

Statistical Analysis

Normality of data was verified and outliers were identified using the UNIVARIATE procedure in SAS. Data were analyzed using the PROC MIXED procedure in SAS (SAS Inst. Inc., Cary, NC) with the experimental unit being the pen. The fixed effects of the model was supplemental Val and the random effect was block. The LSMEANS procedure was used to calculate mean values for treatment. Orthogonal–polynomial contrasts were used to determine linear and quadratic effects of L-Val or Val-FB levels on response criteria. A contrast statement was also used to compare effects of the 2 sources of Val on response criteria. Using the GLM procedure in SAS, a multivariate linear regression model based on ADG, G:F, or final BW (overall treatment replicates) data was used to determine the RBV of Val in Val-FB using Val in L-Val as the standard (Littell et al., 1997). The following linear equation was used:

$$y = a + b_1x_1 + b_2x_2,$$

where y is growth performance variables (ADG, G:F, and final BW), a is the common intercept, b_1 is the slope of L-Val, x_1 is the supplemental amount of L-Val, b_2 is the slope of Val-FB, and x_2 is the supplemental amount of Val-FB. The RBV in Val-FB using L-Val as the standard were calculated by the ratio of their linear slopes [100 × (b_2/b_1)]. The confidence intervals for the true RBV value were obtained using the RBV estimate and the estimated margin of error according to Littell et al. (1997). Differences in LSMEANS were considered significant at $P < 0.05$, whereas $0.05 \leq P < 0.10$ was considered a tendency.

Results

Addition of either L-Val or Val-FB to the basal diet increased (linear and quadratic, $P < 0.01$) ADG, G:F, and final BW, whereas ADFI decreased linearly ($P \leq 0.01$) as both Val sources were added to the diets (Table 4). Final BW and ADG were also greater ($P < 0.01$) for pigs fed diets supplemented with Val-FB compared with pigs fed diets supplemented with L-Val.

Blood urea nitrogen concentration was reduced (linear and quadratic, $P < 0.01$) as L-Val or Val-FB was added to the basal diet, but there was no difference in BUN between the 2 sources of supplemental Val (Table 5). There was a tendency for plasma

Table 4. Growth performance of pigs fed a Val-deficient basal diet or diets containing increasing Val from L-Val or Val-FB[1]

								P-value				
		L-Val			Val-FB[2]			Pooled SEM	L-Val		Val-FB		
Item	Basal diet								Linear	Quadratic	Linear	Quadratic	L-Val vs. Val-FB
Added Val, %		0.08	0.16	0.24	0.08	0.16	0.24						
Initial BW, kg	6.89	6.88	6.87	6.87	6.85	6.83	6.90		–	–	–	–	–
Final BW, kg	8.71	9.94	10.98	11.41	10.14	11.64	12.18	0.42	<0.01	0.05	<0.01	0.03	<0.01
ADG, g	91	153	206	227	165	241	264	12.85	<0.01	0.04	<0.01	0.01	<0.01
ADFI, g	491	417	416	386	458	408	396	30.02	0.01	0.42	<0.01	0.69	0.52
G:F	0.19	0.38	0.55	0.56	0.37	0.61	0.64	0.04	<0.01	0.03	<0.01	0.06	0.23

[1]Results represent data from 224 weanling pigs allotted to 7 diets with 8 replicate pens per diets and 4 pigs per pen. Pigs were fed experimental diets for 20 d. Each least squares mean represents 8 observations, except for the diets with 0.16 or 0.24 L-Val, or 0.24 L-Val-FB, which had 7 observations.
[2]Val-FB = L-Val with fermentation biomass.

Table 5. Blood urea nitrogen and concentrations of plasma free AA in pigs fed diets containing increased levels of L-Val or Val-FB[1]

Item	Basal diet	L-Val			Val-FB			*P-value*					
								L-Val			Val-FB		
Supplemental Val, %		0.08	0.16	0.24	0.08	0.16	0.24	Pooled SEM	Linear	Quadratic	Linear	Quadratic	L-Val vs. Val-FB
BUN[2], mg/dL	6.00	3.59	1.74	2.00	3.56	1.93	2.06	0.26	<0.01	<0.01	<0.01	<0.01	0.71
Indispensable AA, µg/Ml													
Arg	15.61	9.21	10.65	10.79	11.82	11.41	11.26	1.30	0.02	0.01	0.02	0.16	0.23
His	11.53	8.50	9.49	10.61	9.79	7.95	10.20	1.22	0.74	0.08	0.28	0.10	0.81
Ile	8.15	5.86	12.92	13.35	5.86	12.69	15.26	1.61	<0.01	0.39	<0.01	0.13	0.66
Leu	23.18	21.31	31.47	30.72	25.99	30.09	35.07	3.02	0.01	0.85	<0.01	0.71	0.30
Lys	51.21	32.36	71.14	83.19	40.35	76.24	64.77	12.93	0.01	0.20	0.16	0.97	0.85
Met	12.57	11.27	18.49	21.43	8.63	31.14	32.98	4.51	0.09	0.64	<0.01	0.52	0.06
Phe	11.41	10.07	10.87	10.91	10.98	11.77	12.33	1.07	0.88	0.52	0.44	0.63	0.22
Thr	132.61	150.62	170.95	164.18	156.88	192.04	147.11	19.47	0.15	0.49	0.34	0.06	0.82
Trp	11.66	8.01	11.41	9.71	8.44	9.00	11.03	1.85	0.75	0.58	0.86	0.14	0.87
Val	6.63	5.41	12.81	24.09	5.94	17.57	26.64	2.53	<0.01	0.01	<0.01	0.04	0.18
Dispensable AA, µg/Ml													
Ala	60.70	51.03	84.23	76.51	61.12	75.57	76.49	7.59	<0.01	0.88	0.04	0.97	0.93
Asp	2.40	2.28	3.44	2.81	2.72	2.77	3.42	0.33	0.06	0.40	0.02	0.55	0.60
Cys	0.37	0.86	3.13	3.56	0.83	3.62	3.85	0.44	<0.01	0.94	<0.01	0.79	0.48
Glu	31.12	29.43	45.04	34.41	36.14	35.61	40.75	4.27	0.12	0.22	0.08	0.98	0.68
Gly	119.76	98.21	111.49	89.89	127	103.61	81.77	10.02	0.07	0.99	<0.01	0.13	0.58
Pro	31.23	28.25	40.64	39.73	33.80	39.56	42.65	3.81	0.02	0.77	0.01	0.94	0.41
Ser	21.35	20.95	22.40	17.38	22.51	19.00	19.29	2.12	0.23	0.24	0.28	0.83	0.99
Tyr	15.39	13.36	15.28	14.26	16.65	16.37	19.33	1.78	0.85	0.78	0.12	0.45	0.06
Total AA, µg/mL	572.55	505.73	689.68	660.11	593.12	696.01	676.63	63.96	0.08	0.74	0.11	0.73	0.44

[1]Results represent data from 224 weanling pigs allotted to 7 diets with 8 replicate pens per diets and 4 pigs per pen. Pigs were fed experimental diets for 20 d. Each least squares mean represents 8 observations.

[2]BUN = blood urea nitrogen.

concentrations of Met and Tyr to be greater ($P = 0.06$) for pigs fed diets supplemented with Val-FB compared with pigs fed diets supplemented with L-Val, but for all other AA, no differences between the 2 sources of Val were observed. Feeding diets with increasing concentrations of L-Val resulted in increased (linear and quadratic, $P < 0.05$) concentration of Arg in plasma, and the concentration of Val in plasma also increased (linear and quadratic, $P \leq 0.01$). There was also an increase (linear, $P < 0.05$) in plasma concentrations of Ile, Leu, Lys, Ala, Cys, and Pro, but a tendency (quadratic, $P = 0.08$) for a reduction in plasma concentration of His as Val from L-Val increased in the diets. A tendency for increased (linear, $P < 0.10$), plasma concentrations of Met, Asp, and total AA and a tendency for reduced (linear, $P = 0.07$) concentration of Gly were also observed as dietary Val from L-Val increased.

Pigs fed diets supplemented with Val-FB had reduced (linear, $P < 0.05$) concentrations of Arg and Gly in plasma, but increased (linear, $P < 0.05$) concentrations of Ile, Leu, Met, Ala, Asp, Cys, and Pro as Val-FB inclusion in diets increased. The concentration of Val in plasma was also increased (linear and quadratic, $P < 0.05$) by increasing Val-FB in the diets. There was a tendency for increased concentrations of Thr (quadratic, $P = 0.06$) and Glu (linear, $P = 0.08$) in the plasma of pigs fed diets containing increased concentrations of Val-FB.

The RBV of Val in Val-FB as determined by a linear slope ratio regression based on ADG, G:F, or final BW as response criteria was 146%, 135%, and 143%, respectively, compared with the standard L-Val (Figures 1–3). The 95% confidence intervals of the RBV were 99% to 191%, 83% to 187%, and 70% to 217%, respectively, for ADG, G:F, and final BW.

Discussion

In corn-soybean meal diets fed to growing pigs, Val is the fifth-limiting AA (Figueroa et al., 2003) and most research with branched-chain AA has been conducted with Val or Ile (Kidd et al., 2013). Unlike other AA, most deamination of branced chain AA occurs in skeletal muscle because the enzyme needed to deaminate AA, branced chain AA transferase, primarily is located in skeletal muscle (Shimomura et al., 2006). The optimal SID Val:Lys ratio for weaned pigs has been estimated to be between 63% and 70% (Wiltafsky et al., 2009; Barea et al., 2009; NRC, 2012; Rostagno et al., 2017), but the risk of pigs developing diarrhea is reduced if low-CP diets are used (Nørgaard et al., 2012). Formulating low-CP diets often makes it necessary to include crystalline AA in the diet, and by supplementing diets with crystalline AA, it is possible to maintain animal growth performance in pigs fed diet with reduced CP (Lordelo et al., 2008). There is, therefore, increased interest in feeding low-CP diets to pigs, which has increased the need for adding supplemental Val to the diets.

Commercial production of L-Val has increased using large-scale fermentation technologies. Industrial production of L-Val may be accomplished using a number of microorganisms in the fermentation process, including *Bacillus, Serratia marcescens*, *Brevibacterium flavum,* and *Corynebacterium glutamicum* (Wang et al., 2018). At the conclusion of fermentation, crystalline L-Val is extracted from the fermentation biomass, and the fermentation biomass is a waste product. However, if the entire biomass is spray dried, a Val-rich feed ingredient is generated without having to extract and purify L-Val to crystalline L-Val. Therefore, Val-FB is produced by a direct spray granulation of the fermentation broth with biomass without prior evaporation due to the high viscosity of the broth. The final product, which is not commercially available yet, is in granulate form with a brownish color.

The concentration of digestible Lys in dried fermentation biomass from Lys production is greater than in other protein sources, which indicates that the biomass from Lys production retained some Lys after the purification step in L-Lys production (Sulabo et al., 2013). Likewise, Thr biomass is a rich source of digestible Thr and Thr biomass has a greater SID of all indispensable AA compared with fish meal (Almeida et al., 2014b). However, in the previous research, only the Lys or Thr left

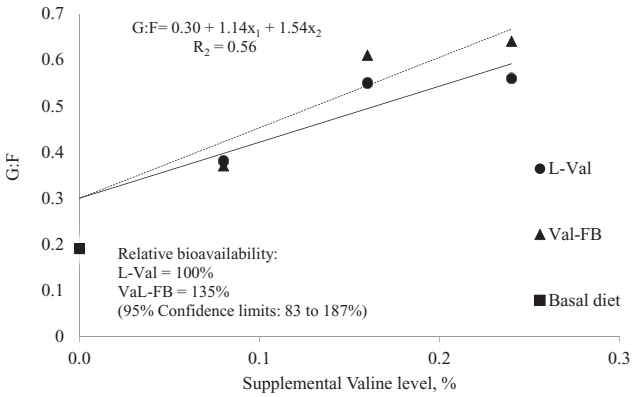

Figure 2. Bioavailability of Val in Val-FB relative to Val in L-Val using G:F as the response criteria. The SEM was 25.86.

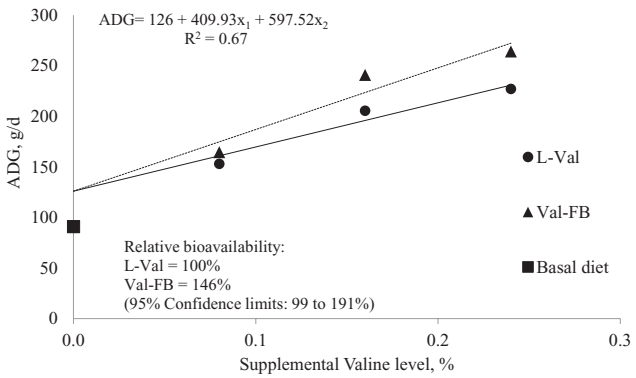

Figure 1. Bioavailability of Val in Val-FB relative to Val in L-Val using ADG as the response criteria. The SEM was 22.92.

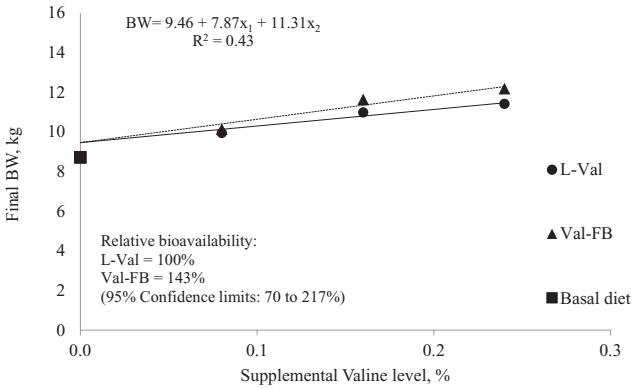

Figure 3. Bioavailability of Val in Val-FB relative to Val in L-Val using final BW as the response criteria. The SEM was 36.77.

in the biomass after extraction of L-Lys or L-Thr was included in the dried biomass product. In this case, the entire biomass that included all produced L-Val was dried and used, which is the reason a biomass product with 64.5% L-Val was generated.

Although the RBV of Val in Val-FB as determined by ADG, G:F, or final BW compared with L-Val was 146%, 135%, and 143%, respectively, the 95% confidence intervals reached 100% regardless of which response variable was used. This indicates that Val from Val-FB was at least as bioavailable as that of Val from L-Val. The relative wide confidence intervals that were calculated for the slopes representing the RBV of Val illustrates the wide variability among pens, but this observation is in agreement with results from other studies that evaluated the RBV of L-Met (Htoo and Morales, 2016) or the RBV of L-Lys (Htoo et al., 2016). Nevertheless, it was expected that the RBV of Val in Val-FB relative to L-Val was 100% because the same source of Val was present in both ingredients, and the present data confirmed this hypothesis.

The greater final BW and ADG of pigs fed Val-FB compared with pigs fed L-Val may be a result of the presence of components other than Val in the biomass. The Val-FB contains approximately 13.6% additional indispensable and dispensable AA and these AA were disregarded in diet formulation, but because all AA other than Val in all diets were included to meet NRC requirements, it is unlikely that the additional AA influenced growth performance of the pigs. However, it is possible that the biomass contained beneficial nutrients other than AA from fermentation, which resulted in the increased ADG (Sulabo et al., 2013).

The decrease in ADFI in pigs fed either source of Val may be a result of pigs fed the Val-deficient basal diet tried to compensate for the Val deficiency by increasing feed intake, but as Val concentration in the diets increased the need for the increased feed intake was reduced. The increased ADG and G:F that were observed as Val in the diets increased was expected, because this is usually observed if a deficiency of a dietary nutrient is ameliorated. An increase in ADG and G:F was also reported as a result of adding L-Thr to a Thr-deficient diet (Zhang et al., 2013).

The decrease in BUN that was observed as Val increased in the diets is a classical response to a reduced deficiency of an AA because BUN concentrations are elevated if one or more AA are deficient in a diet (Zhang et al., 2013). Blood urea nitrogen reflects the metabolic status of AA in the animal and a decrease in BUN is usually a result of increased protein synthesis (Zhang et al., 2013). The reduction in BUN that was observed as dietary Val increased is, therefore, an indication of increased protein synthesis as a result of increased Val in the diets. This result concurs with data from an experiment evaluating SID Ile:Lys ratios in growing pigs where BUN values also were reduced as more Ile was added to an Ile-deficient diet (Htoo et al., 2014).

The increased Val concentration in plasma that was observed as Val increased in the diets was expected. This result is in agreement with published data (Wiltafsky et al., 2010; Xu et al., 2018) and indicates that the additional Val that was provided from both sources of Val was efficiently absorbed from the gastrointestinal tract (Xu et al., 2018). In addition to Val, the concentrations of some other AA were also increased in plasma, which may be a result of increased protein synthesis as dietary Val increased, because increased protein synthesis may have required greater transportation of AA from the liver to skeletal muscle and other tissues. The increase in plasma concentrations of AA corresponded with the improvement in ADG and G:F and the reduced BUN that were observed as dietary Val increased.

In conclusion, Val-FB can be used as a source of Val in diets for pigs. Using ADG, G:F, or final BW as the response criteria, the linear regression estimated a RBV of at least 100% for Val in Val-FB relative to Val in L-Val. Pigs fed the diets supplemented with Val-FB had greater ADG and final BW than pigs fed diets supplemented with the same amount of L-Val, which may be a result of the presence of other nutrients in Val-FB.

Literature Cited

Almeida, F. N., J. K. Htoo, J. Thomson, and H. H. Stein. 2014a. Digestibility by growing pigs of amino acids in heat-damaged sunflower meal and cottonseed meal. *J. Anim. Sci.* **92**:585–593. doi:10.2527/jas.2013–6769

Almeida, F. N., R. C. Sulabo, and H. H. Stein. 2014b. Amino acid digestibility and concentration of digestible and metabolizable energy in a threonine biomass product fed to weanling pigs. *J. Anim. Sci.* **92**:4540–4546. doi:10.2527/jas.2013-6635

AMINODat® 5.0. Platinum version. 2016. Evonik Degussa GmbH, Hanau-Wolfgang, Germany.

AOAC Int. 2007. *Official methods of analysis of AOAC international*. 18th ed. AOAC international, Gaithersburg, MD.

Barea, R., L. Brossard, N. Le Floc'h, Y. Primot, D. Melchior, and J. van Milgen. 2009. The standardized ileal digestible valine-to-lysine requirement ratio is at least seventy percent in postweaned piglets. *J. Anim. Sci.* **87**:935–947. doi:10.2527/jas.2008-1006

Figueroa, J. L., A. J. Lewis, P. S. Miller, R. L. Fischer, and R. M. Diedrichsen. 2003. Growth, carcass traits, and plasma amino acid concentrations of gilts fed low-protein diets supplemented with amino acids including histidine, isoleucine, and valine. *J. Anim. Sci.* **81**:1529–1537. doi:10.2527/2003.8161529x

Htoo, J. K., and J. Morales. 2016. Bioavailability of L-Methionine relative to DL-Methionine as a methionine source for weaned pigs. *J. Anim. Sci.* **94**:249–252. doi:10.2527/jas.2015–9796

Htoo, J. K., J. P. Oliveira, L. F. T. Albino, M. I. Hannas, N. A. A. Barbosa, and H. S. Rostagno. 2016. Bioavailability of L-lysine HCl and L-lysine sulfate as lysine sources for growing pigs. *J. Anim. Sci.* **94**:253–256. doi:10.2527/jas.2015–9797

Htoo, J. K., C. L. Zhu, L. Huber, C. F. de Lange, A. D. Quant, B. J. Kerr, G. L. Cromwell, and M. D. Lindemann. 2014. Determining the optimal isoleucine:lysine ratio for ten- to twenty-two-kilogram and twenty-four- to thirty-nine-kilogram pigs fed diets containing nonexcess levels of leucine. *J. Anim. Sci.* **92**:3482–3490. doi:10.2527/jas.2013-6934

Kidd, M. T., P. B. Tillman, P. W. Waldroup, and W. Holder. 2013. Feed-grade amino acid use in the United States: The synergetic inclusion history with linear programming. *J. Appl. Poult. Res.* **22**:583–590. doi:10.3382/japr.2012-00690

Littell, R. C., P. R. Henry, A. J. Lewis, and C. B. Ammerman. 1997. Estimation of relative bioavailability of nutrients using SAS procedures. *J. Anim. Sci.* **75**:2672–2683. doi:10.2527/1997.75102672x

Llames, C. R., and J. Fontaine. 1994. Determination of amino acids in feeds: collaborative study. *J. AOAC Int.* **77**:1362–1402.

Lordelo, M. M., A. M. Gaspar, L. Le Bellego, and J. P. Freire. 2008. Isoleucine and valine supplementation of a low-protein corn-wheat-soybean meal-based diet for piglets: growth performance and nitrogen balance. *J. Anim. Sci.* **86**:2936–2941. doi:10.2527/jas.2007-0222

Nørgaard, J. V., N. Canibe, B. Nielsen, D. Carlson, I. Knap, M. D. Cantor, and H. D. Poulsen. 2012. First studies on a new concept for amino acid provision through B. subtilis in situ valine production in young pigs. *Livest. Sci.* **147**:33–39. doi:https://doi.org/10.1016/j.livsci.2012.03.016

NRC. 2012. *Nutrient requirements of swine*. 11th rev. ed. Natl. Acad. Press, Washington, D.C.

Rostagno, H. S., L. F. T. Albino, M. I. Hannas, J. L. Donzele, S. N. K., G. F. Perazzo, A. Saraiva, M. Abreu, L. T., P. B. Rodrigues,

R. F. Oliveira, S. L. T. Barreto, *et al.* 2017. *Brazilian tables for poultry and swine. Composition of feedstuffs and nutritional requirements*. 4th ed. Federal University of Vicosa Department of Animal Science, Vicosa, MG, Brazil.

Shimomura, Y., Y. Yamamoto, G. Bajotto, J. Sato, T. Murakami, N. Shimomura, H. Kobayashi, and K. Mawatari. 2006. Nutraceutical effects of branched-chain amino acids on skeletal muscle. *J. Nutr*. **136**:529S–532S. doi:10.1093/jn/136.2.529S

Sulabo, R. C., J. K. Mathai, J. L. Usry, B. W. Ratliff, D. M. McKilligan, J. D. Moline, G. Xu, and H. H. Stein. 2013. Nutritional value of dried fermentation biomass, hydrolyzed porcine intestinal mucosa products, and fish meal fed to weanling pigs. *J. Anim. Sci*. **91**:2802–2811. doi:10.2527/jas.2012–5327

Wang, X., H. Zhang, and P. J. Quinn. 2018. Production of L-valine from metabolically engineered Corynebacterium glutamicum. *Appl. Microbiol. Biotechnol*. **102**:4319–4330. doi:10.1007/s00253-018-8952-2

Wiltafsky, M. K., J. Bartelt, C. Relandeau, and F. X. Roth. 2009. Estimation of the optimum ratio of standardized ileal digestible isoleucine to lysine for eight- to twenty-five-kilogram pigs in diets containing spray-dried blood cells or corn gluten feed as a protein source. *J. Anim. Sci*. **87**:2554–2564. doi:10.2527/jas.2008-1320

Wiltafsky, M. K., M. W. Pfaffl, and F. X. Roth. 2010. The effects of branched-chain amino acid interactions on growth performance, blood metabolites, enzyme kinetics and transcriptomics in weaned pigs. *Br. J. Nutr*. **103**:964–976. doi:10.1017/S0007114509992212

Xu, Y. T., X. K. Ma, C. L. Wang, M. F. Yuan, and X. S. Piao. 2018. Effects of dietary valine:lysine ratio on the performance, amino acid composition of tissues and mRNA expression of genes involved in branched-chain amino acid metabolism of weaned piglets. *Asian-Australas. J. Anim. Sci*. **31**:106–115. doi:10.5713/ajas.17.0148

Zhang, G. J., C. Y. Xie, P. A. Thacker, J. K. Htoo, and S. Y. Qiao. 2013. Estimation of the ideal ratio of standardized ileal digestible threonine to lysine for growing pigs (22–50 kg) fed low crude protein diets supplemented with crystalline amino acids. *Anim. Feed Sci. Technol*. **180**:83–91. doi:10.1016/j.anifeedsci.2013.01.006