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Amino acid digestibility and concentration of digestible and metabolizable energy in a threonine biomass product fed to weanling pigs[1]

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ABSTRACT: Production of crystalline L-Thr results in the generation of a Thr biomass that contains more than 80% CP, 5.20% Lys, 5.10% Val, 4.52% Thr, 4.15% Ile, and 1.06% Trp. This Thr biomass product can possibly be used as a feed ingredient in diets fed to weanling pigs, but there is little information about the nutritional value of this product. The objective of this work was to determine the AA digestibility and energy concentration in Thr biomass and to compare these values to values obtained for fish meal in diets fed to pigs. The apparent ileal digestibility (AID) and the standardized ileal digestibility (SID) of CP and AA were determined in Exp. 1. Nine pigs (initial BW: 13.4 ± 2.5 kg) were equipped with a T-cannula in the distal ileum and allotted to a triplicated 3 × 3 Latin square design with 3 diets and 3 periods in each square. One diet contained 20.0% Thr biomass as the sole source of AA, and a second diet contained 25.0% fish meal as the sole source of AA. The last diet was a N-free diet that was used to measure basal endogenous losses of AA and CP. Results indicated that the AID and SID of all AA except Trp, Gly, and Pro were greater ($P < 0.05$) in Thr biomass than in fish meal. In Exp. 2, 24 pigs (initial BW: 18.1 ± 3.5 kg) were placed in metabolism cages and randomly allotted to 3 diets. The first diet contained 96.4% corn, the second diet contained 79.3% corn and 17.0% Thr biomass, and the third diet contained 75.3% corn and 24.0% fish meal. Total collection of feces and urine was performed for 5 d after a 5-d adaptation period, and all samples of ingredients, diets, feces, and urine were analyzed for GE. Digestible energy and ME were then calculated. The DE in the Thr biomass was greater ($P < 0.05$) than in fish meal and corn (4,935 vs. 3,938 and 3,939 kcal DE/kg DM, respectively), and the ME in the Thr biomass was also greater ($P < 0.05$) than in fish meal and corn (4,335 vs. 3,508 and 3,839 kcal ME/kg DM, respectively). Results from these experiments indicate that Thr biomass is an excellent source of AA and ME. Therefore, the Thr biomass is a viable ingredient that can be used as an alternative to fish meal and possibly other animal proteins in diets for pigs.

Keywords: amino acids, digestibility, energy, fish meal, pig, threonine biomass

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INTRODUCTION

Select menhaden fish meal is often used in diets fed to weanling pigs because of the high concentration and favorable balance of digestible AA in fish meal (Stoner et al., 1990). However, responses to inclusion of fish meal in weanling pig diets have been inconsistent, which may reflect variations in quality (Kim and Easter, 2001; Sulabo et al., 2009). The increasing cost of select menhaden fish meal as well as of other animal protein sources has made it necessary to evaluate alternative protein and energy sources that can be used as substitutes for animal proteins in diets fed to weanling pigs.

Crystalline L-Thr is often added to swine diets to balance indispensable AA. The commercial production of synthetic L-Thr has increased because of developments in large-scale fermentation technologies (Kramer, 2005). Synthetic L-Thr is produced via direct fermentation of mutant strains of *Escherichia coli*, *Serratia marcescens*, *Brevibacterium flavum*, and *Corynebacterium glutamicum* using carbohydrates as substrates (Chen et al., 2009). At the conclusion of the fermentation process, crystalline L-Thr is extracted from the fermentation biomass, but relatively large quantities of residual biomass that are rich in CP and indispensable AA are generated. This biomass, which has been approved under the Association of American

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Feed Control Officials (2011; number 36.15) as a protein source, can possibly be used as an alternative to fish meal in diets fed to pigs, but at this point, no experiments have been conducted to determine the nutritional value of the microbial biomass. The objectives of these experiments were to determine the digestibility of AA and the concentration of DE and ME in microbial biomass generated from the production of crystalline L-Thr and to compare these values to values obtained for fish meal in diets fed to weanling pigs.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocols for the experiments. Pigs used in both experiments originated from the matings of G-Performer boars to F-25 females (Genetiporc, Alexandria, MN). The Thr biomass used in the experiments was sourced from Archer Daniels Midland Co. (Decatur, IL), and the fish meal (select menhaden) was sourced from Omega Protein (Houston, TX; Table 1). Corn was obtained from a local source in Champaign, Illinois. The same batches of Thr biomass and fish meal were used in both experiments.

Experiment 1: AA Digestibility

Animals, Diets, and Experimental Design. Nine weanling barrows (initial BW: 13.4 ± 2.5 kg) were equipped with a T-cannula in the distal ileum and allotted to a triplicated 3 × 3 Latin square design with 3 diets and 3 periods in each square. Pigs were housed individually in fully slatted pens (1.2 × 1.5 m) in an environmentally controlled room. A feeder and a nipple drinker were installed in each pen.

Three diets were prepared (Tables 2 and 3). One diet contained the Thr biomass (20%) as the sole source of AA, and a second diet contained fish meal (25%) as the sole source of AA. The inclusion levels of Thr biomass and fish meal were chosen to provide approximately 18% CP in each diet. The third diet was a N-free diet that was used to measure basal endogenous losses of AA and protein. Vitamins and minerals were included in all diets to meet or exceed requirement estimates (NRC, 1998). All diets also contained 0.4% chromic oxide as an indigestible marker.

Feeding and Sample Collection. All pigs were fed at a level of 2.5 times the maintenance energy requirement (i.e., 106 Mcal ME/kg$^{0.75}$; NRC, 1998) assuming that the Thr biomass had the same ME as fish meal. Daily feed allotments were divided into 2 equal meals. Water was available at all times throughout the experiment. Pig weights were recorded at the beginning and at the end of each period, and the quantities of feed supplied each day were recorded. The initial 5 d of each period were considered an adaptation period to the diet. Ileal digesta were collected for 8 h on d 6 and 7 by attaching a plastic bag to the opened cannula barrel, which allowed for collection of digesta, flowing into the bag. Bags were removed whenever they were filled with digesta or at least once every 30 min and were immediately stored at –20°C to prevent bacterial degradation of the AA in the digesta. On the completion of 1 experimental period, animals were deprived of feed overnight, and the following morning, a new experimental diet was offered.

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

	Ingredient		
Item	Thr biomass	Fish meal	Corn
DM, %	95.36	89.67	91.74
GE, kcal/kg	5549	4397	3884
Ash, %	3.36	19.29	0.88
CP (N × 6.25), %	81.80	65.62	7.27
Acid hydrolyzed ether extract, %	8.44	10.19	4.15
Indispensable AA, %			
Arg	5.11	3.70	—
His	1.83	1.43	—
Ile	4.15	2.64	—
Leu	7.24	4.37	—
Lys	5.20	4.76	—
Met	2.15	1.68	—
Phe	3.45	2.38	—
Thr	4.52	2.39	—
Trp	1.06	0.63	—
Val	5.10	3.02	—
Dispensable AA, %			
Ala	5.78	3.89	—
Asp	8.31	5.55	—
Cys	0.74	0.48	—
Glu	9.40	7.63	—
Gly	3.83	4.66	—
Pro	2.77	2.68	—
Ser	2.71	1.97	—
Tyr	2.87	1.83	—
Total AA	76.23	56.20	—

Sample Analysis and Data Processing. At the conclusion of the experiment, ileal samples were thawed and mixed, and a subsample was collected for chemical analysis. Samples of the Thr biomass, fish meal, and each diet were also collected. Digesta samples were lyophilized and finely ground before chemical analysis. All samples of ingredients, diets, and digesta were analyzed for DM (method 930.15; AOAC International, 2007), CP (method 990.03; AOAC International, 2007), and AA (method 982.30 E (a, b, c); AOAC International, 2007). Diets and ileal digesta were also analyzed for chromium (method 990.08; AOAC International, 2007). Ingredients were also analyzed for total fat by acid hydrolysis using 3 *N* HCl (Sanderson, 1986) followed

Table 2. Composition of diets (as-fed basis), Exp. 1

	Diet		
Ingredient, %	Thr biomass	Fish meal	N free
Thr biomass	20.00	—	—
Fish meal	—	25.00	—
Soybean oil	4.00	—	4.00
Solka-Floc[1]	—	—	4.00
Monocalcium phosphate	1.00	—	2.40
Limestone	2.00	—	0.50
Sucrose	20.00	20.00	20.00
Chromic oxide	0.40	0.40	0.40
Cornstarch	51.90	53.90	67.50
Magnesium oxide	—	—	0.10
Potassium carbonate	—	—	0.40
Sodium chloride	0.40	0.40	0.40
Vitamin and mineral premix[2]	0.30	0.30	0.30
Total	100.00	100.00	100.00

[1]Fiber Sales and Development Corp., Urbana, OH.

[2]Provided the following quantities of vitamins and microminerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfate, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 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 as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu as copper sulfate, 10 mg; Fe as iron sulfate, 125 mg; I as potassium iodate, 1.26 mg; Mn as manganese sulfate, 60 mg; Se as sodium selenite, 0.3 mg; and Zn as zinc oxide, 100 mg.

Table 3. Analyzed nutrient composition (as-fed basis) of experimental diets, Exp. 1

	Diet		
Item	Thr biomass	Fish meal	N free
DM, %	93.39	92.15	91.48
CP (N × 6.25), %	17.96	18.82	0.39
Indispensable AA, %			
Arg	0.98	0.99	0.01
His	0.36	0.38	—
Ile	0.82	0.73	0.01
Leu	1.46	1.23	0.02
Lys	1.00	1.32	0.01
Met	0.41	0.47	—
Phe	0.69	0.67	0.01
Thr	1.33	0.67	0.01
Trp	0.21	0.18	0.04
Val	1.01	0.84	0.02
Mean	8.27	7.48	0.13
Dispensable AA, %			
Ala	1.17	1.08	0.02
Asp	1.67	1.54	0.02
Cys	0.17	0.14	—
Glu	2.07	2.18	0.04
Gly	0.77	1.24	0.01
Pro	0.57	0.71	0.02
Ser	0.55	0.56	0.01
Tyr	0.51	0.45	0.01
Mean	7.54	8.07	0.20
All AA	15.81	15.55	0.33

by crude fat extraction with petroleum ether (method 2003.06, AOAC International, 2007) on a Soxtec 2050 automated analyzer (FOSS North America, Eden Prairie, MN), for GE using bomb calorimetry (model 6300, Parr Instruments, Moline, IL), and for dry ash (method 942.05; AOAC International, 2007).

Values for apparent ileal digestibility (**AID**), basal endogenous losses, and standardized ileal digestibility (**SID**) of CP and AA in the Thr biomass and in fish meal were calculated (Stein et al., 2007). Data were analyzed by ANOVA using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The presence of outliers was tested using the UNIVARIATE procedure of SAS. The model included diet as the fixed effect and replicate as the random effect. Least squares means were calculated for each independent variable. When treatment was a significant source of variation, means were separated using the PDIFF option of SAS. The pig was the experimental unit for all calculations, and the α level used to determine significance between means was 0.05.

Experiment 2: Energy Measurements

Animals, Diets, and Experimental Design. Twenty-four growing barrows (initial BW: 18.1 ± 3.5 kg) were used to measure DE and ME of the Thr biomass, fish meal, and corn. Pigs were housed in metabolism cages and allotted to 3 dietary treatments using a randomized complete block design with 8 pigs per treatment. A feeder and a nipple drinker were installed in each metabolism cage. The floor of the cages was fully slatted. A screen floor and a urine tray were installed below the slatted floor to allow for total, but separate, collection of feces and urine.

Three diets were prepared for this experiment (Table 4). The first diet contained 96.4% (as-fed basis) corn. The second diet contained 79.3% corn and 17.0% Thr biomass (as-fed basis), whereas the third diet contained 75.3% corn and 24.0% fish meal (as-fed basis). Diets 2 and 3 were formulated to contain approximately 21% CP. Vitamins and minerals were included in all diets to meet or exceed the estimated nutrient requirements for weanling pigs (NRC, 1998).

Feeding and Sample Collection. Pigs were fed daily at 3 times their estimated requirement for maintenance energy (i.e., 106 kcal ME per $kg^{0.75}$; NRC, 1998). The daily feed allocations were divided into 2 equal meals that were provided at 0800 and 1700 h. Water was available at all times. Pig feed allowances were recorded, and unconsumed feed in the feeders was collected before each feeding, and the weight was recorded.

Diets were fed for 12 d with the initial 5 d serving as an adaptation period to the diets. Feces originating from

Table 4. Composition of diets (as-fed basis), Exp. 2

	Diets		
Item	Corn	Thr biomass	Fish meal
Ingredients, %			
Ground corn	96.40	79.30	75.30
Thr biomass	—	17.00	—
Fish meal	—	—	24.00
Monocalcium phosphate	1.70	1.00	—
Limestone	1.20	2.00	—
Sodium chloride	0.40	0.40	0.40
Vitamin and mineral premix[1]	0.30	0.30	0.30
Energy, DM, and nutrients (analyzed)			
DM, %	87.53	89.24	88.25
CP (N × 6.25), %	7.27	21.18	21.43
AEE,[2] %	3.31	4.59	5.25
GE, kcal/kg	3731	4054	3881
Indispensable AA, % (calculated)			
Arg	0.36	1.16	1.17
His	0.23	0.50	0.52
Ile	0.27	0.93	0.84
Leu	0.93	1.99	1.77
Lys	0.24	1.08	1.33
Met	0.17	0.51	0.54
Phe	0.38	0.90	0.86
Thr	0.27	0.99	0.78
Trp	0.06	0.23	0.20
Val	0.37	1.17	1.01

[1]Provided the following quantities of vitamins and microminerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,128 IU; vitamin D_3 as cholecalciferol, 2,204 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione nicotinamide bisulfate, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.58 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 as nicotinamide and nicotinic acid, 44 mg; folic acid, 1.58 mg; biotin, 0.44 mg; Cu as copper sulfate, 10 mg; Fe as iron sulfate, 125 mg; I as potassium iodate, 1.26 mg; Mn as manganese sulfate, 60 mg; Se as sodium selenite, 0.3 mg; and Zn as zinc oxide, 100 mg.

[2]AEE = acid hydrolyzed ether extract.

the feed that was fed from d 6 to 10 were collected using the marker to marker approach (Adeola, 2001). Feces were collected twice daily and stored at –20°C until the conclusion of the experiment. Urine was also collected twice daily from d 6 to 10 using urine buckets placed under the metabolism cages, which allowed for total collection. Buckets were emptied in the morning and afternoon, and a preservative of 50 mL of 6 *N* sulfuric acid was added to each bucket when it was emptied. All collected urine samples were weighed, and a 10% subsample was collected and stored at –20°C.

Sample Analysis and Data Processing. At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet, and a subsample was collected and lyophilized. Fecal samples were dried in a forced-air oven at 65°C and finely ground before analysis. Diets were analyzed for DM, CP, and acid hydrolyzed fat as explained for Exp. 1. Gross energy was analyzed in ingredients, diets, urine, and fecal samples using bomb calorimetry (model 6300, Parr Instruments, Moline, IL). Urine samples were prepared for analysis as described by Kim et al. (2009). Benzoic acid was used as the standard for calibration. Following chemical analysis, apparent total tract digestibility (**ATTD**) values were calculated for energy in each diet (Widmer et al., 2007). The energy that was excreted in the feces and in the feces and urine was subtracted from the intake of GE to calculate the DE and ME for each diet (Adeola, 2001). The DE and ME in corn were calculated by dividing the DE and ME values for the corn diet by the inclusion rate of corn in the diet. By subtracting the contribution of energy from corn from the energy in the diets containing the Thr biomass or fish meal, the concentrations of DE and ME in the Thr biomass and fish meal were calculated by difference (Adeola, 2001; Widmer et al., 2007). By correcting values for DM, the DE and ME in the ingredient DM were calculated. Data were analyzed as described for Exp. 1.

RESULTS

Experiment 1: AA Digestibility

The concentrations (%) of CP, total AA, and Thr were relatively greater in the Thr biomass than in fish meal (Table 1). The AID for CP was greater ($P < 0.05$) in the Thr biomass than in fish meal (Table 5). The AID for all indispensable AA except Trp was also greater ($P < 0.05$) in the Thr biomass than in fish meal, and the AID of all dispensable AA except Gly and Pro was greater ($P < 0.05$) in the Thr biomass than in fish meal.

The SID of CP and all indispensable AA, except Trp, was greater ($P < 0.05$) in the Thr biomass than in fish meal. Likewise, SID values for all dispensable AA, except Pro, were greater ($P < 0.05$) in the Thr biomass than in fish meal, and the SID of all AA was greater ($P < 0.05$) in the Thr biomass than in fish meal.

Experiment 2: Energy Measurements

The GE intake for pigs fed the diets containing Thr biomass or fish meal was greater ($P < 0.05$) than that for pigs fed the corn diet (Table 6). The fecal excretion of energy from pigs fed the corn diet was less ($P < 0.05$) than that for pigs fed the diet containing the Thr biomass or the diet containing fish meal. Pigs fed the diet containing fish meal excreted more ($P < 0.05$) energy in the urine than pigs fed the diet containing Thr biomass or the corn diet, and urinary energy excretion from pigs fed the diet containing Thr biomass was also greater ($P < 0.05$) than that from pigs fed the corn diet.

The diet containing the Thr biomass had less ($P < 0.05$) ATTD of GE than the diet containing fish meal or the corn diet, but the DE of the diet containing Thr biomass was

Table 5. Apparent ileal digestibility (AID) and standardized ileal digestibility (SID) of CP and AA in Thr biomass and fish meal by weanling pigs, Exp. 1[1]

	AID				SID[2]			
Item	Thr biomass	Fish meal	SEM	*P*-value	Thr biomass	Fish meal	SEM	*P*-value
CP, %	80.0	69.7	2.1	0.004	91.3	80.4	2.1	0.002
Indispensable AA, %								
Arg	87.8	78.7	1.8	0.003	94.9	85.7	1.8	0.003
His	85.7	77.1	1.9	0.006	91.8	82.9	1.9	0.005
Ile	88.2	80.1	2.0	0.005	92.5	84.9	2.0	0.007
Leu	87.8	79.4	2.2	0.006	92.0	84.3	2.2	0.010
Lys	87.2	81.2	1.4	0.007	92.7	85.3	1.4	0.002
Met	89.4	84.3	1.4	0.019	92.0	86.5	1.4	0.013
Phe	85.9	77.1	2.5	0.009	91.2	82.5	2.5	0.010
Thr	88.4	66.1	4.2	0.001	93.9	76.8	4.2	0.002
Trp	88.3	84.7	3.0	0.230	95.0	92.5	3.0	0.371
Val	84.8	74.6	2.9	0.008	90.8	81.7	2.9	0.014
Mean	87.3	78.1	2.0	0.003	92.6	83.8	2.0	0.004
Dispensable AA, %								
Ala	84.1	75.4	2.1	0.010	89.7	81.4	2.1	0.014
Asp	82.2	69.7	1.8	0.001	87.7	75.5	1.8	0.001
Cys	69.1	52.3	5.3	0.010	82.3	68.1	5.3	0.026
Glu	85.4	79.4	1.7	0.026	90.4	84.2	1.7	0.020
Gly	68.5	58.0	4.6	0.140	94.7	74.1	4.6	0.012
Pro	26.2	24.7	22.5	0.900	113.7	96.7	22.5	0.205
Ser	76.2	64.9	3.4	0.020	87.3	75.6	3.4	0.018
Tyr	84.1	74.8	3.0	0.020	89.8	81.2	3.0	0.024
Mean	78.6	67.1	3.2	0.022	93.1	80.5	3.2	0.014
All AA	83.5	72.3	2.3	0.004	93.2	82.0	2.3	0.004

[1]Data are least squares means of 9 observations per treatment.

[2]SID = apparent ileal digestibility of diet + (endogenous losses/intake) × 100%. Endogenous losses (g/kg DMI) of CP and AA were calculated as the following quantities: CP, 21.78; Arg, 0.75; His, 0.24; Ile, 0.38; Leu, 0.66; Lys, 0.59; Met, 0.11; Phe, 0.39; Thr, 0.78; Trp, 0.15; Val, 0.64; Ala, 0.71; Asp, 0.98; Cys, 0.24; Glu, 1.12; Gly, 2.16; Pro, 5.44; Ser, 0.65.

greater ($P < 0.05$) than the DE of the fish meal and corn diets. The ME of the diet containing the Thr biomass was also greater ($P < 0.05$) than the ME of the diet containing fish meal, and the ME of the diet containing fish meal was greater ($P < 0.05$) than the ME of the corn diet.

The Thr biomass contained more ($P < 0.05$) DE than fish meal and corn, but the DE in fish meal was not different from the DE in corn. The ME values for the Thr biomass was greater ($P < 0.05$) than the ME in both fish meal and corn, and the ME of corn was also greater ($P < 0.05$) than the ME in fish meal. This was true when data were calculated on an as-fed basis and on a DM basis.

DISCUSSION

Pigs remained healthy and readily consumed their diets throughout both experiments, thus indicating no issues with palatability of the Thr biomass. The SID of CP and AA in fish meal obtained in the current experiment agree with values reported by Cervantes-Pahm and Stein (2010). The Thr biomass has the unique characteristic of containing high concentrations of several indispens-

Table 6. Daily intake and excretion of energy, apparent total tract digestibility (ATTD) of energy, and concentration of DE and ME in diets and DE and ME in corn, Thr biomass, and fish meal fed to weanling pigs, Exp. 2[1]

Item	Corn	Thr biomass	Fish meal	SEM	*P*-value
Diets					
GE intake, kcal	2747^{x}	2984^{y}	3139^{y}	125	<0.01
GE in feces, kcal	304^{x}	386^{y}	352^{y}	20	<0.01
GE in urine, kcal	61^{x}	123^{y}	132^{z}	9	<0.01
ATTD of GE, %	89.0^{y}	87.1^{x}	88.8^{y}	0.4	<0.01
DE, kcal/kg	3320^{x}	3531^{z}	3444^{y}	14	<0.01
ME, kcal/kg	3236^{x}	3365^{z}	3283^{y}	16	<0.01
Ingredients					
DE, kcal/kg	3444^{x}	4706^{y}	3548^{x}	56	<0.01
DE, kcal/kg DM	3939^{x}	4935^{y}	3957^{x}	59	<0.01
ME, kcal/kg	3357^{y}	4134^{z}	3146^{x}	68	<0.01
ME, kcal/kg DM	3839^{y}	4335^{z}	3508^{x}	71	<0.01

$^{x–z}$Values within a row lacking a common superscript letter are different ($P \leq 0.05$).

[1]Data are means of 8 observations per treatment.

able AA, such as Thr, Lys, Arg, Ile, Val, and Leu. The high concentration of Thr in the Thr biomass indicates that the extraction of Thr from the biomass that is a result of the fermentation process is not 100% efficient. However, the very high SID of all indispensable AA in the Thr biomass also indicates that this product contains highly digestible AA, which may be a result of synthesis of these AA during fermentation. The fact that the SID of all indispensable AA in the Thr biomass are greater than in fish meal indicates that the Thr biomass contains readily available AA that are easily utilized by pigs. Specifically, the Thr biomass is a rich source of digestible Thr. These observations are in agreement with data from Sulabo et al. (2012), in which a dried fermentation biomass derived from L-Lys production contained greater concentrations of digestible AA than fish meal.

The digestibility of energy for corn that was determined in this experiment concurs with previous work (Sauvant et al., 2004; Pedersen et al., 2007), and the digestibility of energy in fish meal that was used in this experiment also agrees with the energy digestibility value reported by Sauvant et al. (2004). The DE and ME of corn that were determined in this experiment agree with previous work (Stein et al., 2004; NRC, 2012), and the DE and ME in fish meal were in close agreement with the DE and ME values published by NRC (1998) and by Sauvant et al. (2004).

The reason the Thr biomass contained more DE than corn and fish meal is mainly that the concentration of GE in the Thr biomass is greater than in the other 2 ingredients. The crude fat concentration of the Thr biomass was less than in fish meal but greater than in corn, which indicates that the difference in GE between the Thr biomass and fish meal most likely is a result of the greater CP concentration and the much lower concentration of ash in Thr biomass than in fish meal. The fact that the protein in the Thr biomass is highly digestible contributes to the greater DE and ME obtained for this ingredient.

The U.S. production of crystalline AA is expected to increase by a compounded annual rate of 3.5% between 2011 and 2016 (Companies and Markets, 2011), and the production of the spent biomass from this industry will therefore, also increase. In the United States, production of crystalline AA is most often associated with the wet corn milling industry because of the need for dextrose as a source of energy for the AA-producing bacteria. The biomass that is produced after AA have been extracted from the fermentation broth is usually included in the corn gluten feed that is produced from wet milling of corn. However, because the digestibility of AA and energy in corn gluten feed is relatively low (Almeida et al., 2011; Rojas et al., 2013), it will be possible to market a higher-value product if the threonine biomass product can be used separately. As a consequence, if the Thr biomass can be kept separate from other coproducts of the wet milling industry, it will be possible to use this ingredient as an AA and energy source in diets fed to pigs.

Conclusion

The Thr biomass that was used in the present experiment was a rich source of CP and indispensable AA that were more digestible than the AA in fish meal. The Thr biomass contained more DE and ME than yellow dent corn and fish meal. Pigs consumed the diets containing the Thr biomass without leaving orts, and no apparent problems with palatability are expected if the Thr biomass is included in diets for pigs. Therefore, the Thr biomass may be used as an alternative to fish meal in diets fed to weanling pigs, but growth assays are needed to determine the optimal inclusion rate of the Thr biomass.

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