Journal of Animal Science, 2020, 1–9

doi:10.1093/jas/skz375
Advance Access publication January 24, 2020
Received: 27 October 2019 and **Accepted:** 21 January 2020
Non Ruminant Nutrition

NON RUMINANT NUTRITION

Torula yeast has greater digestibility of amino acids and phosphorus, but not energy, compared with a commercial source of fish meal fed to weanling pigs

L. Vanessa Lagos and Hans H. Stein[1]

Division of Nutritional Sciences, University of Illinois, Urbana, IL 61801

[1]Corresponding author: hstein@illinois.edu

Abstract

Three experiments were conducted to test the hypothesis that the standardized ileal digestibility (**SID**) of AA, concentrations of DE and ME, and the standardized total tract digestibility (**STTD**) of P in a source of torula yeast are not different from values obtained in Menhaden fish meal. In experiment 1, six weanling barrows (initial BW: 11.7 ± 0.4 kg) were prepared with a T-cannula in the distal ileum and allotted to a replicated 3 × 3 Latin square design with 3 diets and 3 periods. In each period, there were 5 d of adaptation and 2 d of collection. Two cornstarch-based diets using the torula yeast or fish meal as the sole source of AA and a N-free diet were formulated. The SID of CP and all AA was greater ($P < 0.05$) in torula yeast than in fish meal. In experiment 2, 24 weanling barrows (initial BW: 14.4 ± 1.1 kg) were individually housed in metabolism crates and allotted to a corn-based diet or 2 diets based on a mixture of corn and torula yeast or corn and fish meal. Feces and urine samples were collected for 4 d following a 5-d adaptation period. There were 8 replicate pigs per diet and fecal and urine materials were collected. Results of this experiment indicated that there were no differences in the concentration of DE and ME (DM basis) between torula yeast and fish meal. In experiment 3, a total of 32 weanling barrows (initial BW: 11.9 ± 1.1 kg) were allotted to 4 diets and 8 replicate pigs per diet. Pigs were placed in individual metabolism crates. The torula yeast or fish meal were used in 2 diets containing either 0 or 500 units of microbial phytase. Feces samples were collected as described for experiment 2. The STTD of P in torula yeast was greater ($P < 0.05$) than in fish meal, but regardless of ingredient, there was no effect of the inclusion of phytase in the diets. In conclusion, the SID of AA and the STTD of P in torula yeast is greater than in fish meal, but values for the concentration of DE and ME in torula yeast are not different from those in fish meal. Therefore, the torula yeast that was used in the present experiments may be included at the expense of fish meal in diets fed to weanling pigs if the concentration of standardized ileal digestible AA is considered in the formulation.

Key words: amino acids, digestibility, energy, phosphorus, pigs, torula yeast

Introduction

Yeasts, classified in the fungi kingdom, are eukaryotic single-cell microorganisms that can be included in diets for pigs as an alternative to animal proteins (Mateo and Stein, 2007). However, yeast may also have immune stimulating properties that make it more than simply a source of AA (van Heugten et al., 2003). Recently, interests in these products have increased as a result of restrictions in the use of antimicrobial growth promoters in diets for pigs (Shurson, 2018). Thus, several forms of yeast and yeast derivatives are currently available, and research has been conducted to determine their nutritional value and to evaluate the effect of yeast on health status and growth performance of pigs (Shen et al., 2009; Mora et al., 2012; Kim et al., 2014).

Torula is a yeast strain that uses xylose and glucose in wood as substrate (Reed and Nagodawithana, 1991) and it has been

used in swine diets for decades (Figueroa et al., 1990). Torula yeast derived from lignocellulosic biomass is considered a potential sustainable feed ingredient because of its ability to produce high-value products from low-value substrates without competing with the food industry, and does not depend on land, water, or specific climatic conditions as it is the case for plant-based feed ingredients (Øverland and Skrede, 2017). Torula yeast can replace up to 40% of dietary protein from fish meal, soybean meal, rapeseed meal, and potato protein concentrate in diets fed to fish (Øverland et al., 2013) and young pigs (Cruz et al., 2020).

A torula yeast that is grown on forestry by-products has recently been developed and introduced to the swine industry. This single-cell protein has an improved AA profile and a lower carbon-footprint compared with other yeast products because it is produced via fermentation of lignocellulosic material (ARBIOM, 2018). However, no data for the nutritional value of this torula yeast have been published. Therefore, the objective of the current experiments was to test the hypothesis that the standardized ileal digestibility (**SID**) of CP and AA, concentrations of DE and ME, and the standardized total tract digestibility (**STTD**) of P in torula yeast are not different from values obtained in fish meal.

Materials and Methods

Three experiments were conducted following protocols reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Pigs were the offspring of Line 359 boars mated to Camborough sows (PIC, Hendersonville, TN). The torula yeast (Sylpro, Arbiom Inc., Durham, NC) and a commercial source of fish meal (Menhaden Select; Omega Protein, Houston, TX) were used in the 3 experiments (Table 1).

Experiment 1: AA digestibility

Six weanling barrows (initial BW: 11.7 ± 0.4 kg) were equipped with a T-cannula in the distal ileum and allotted to a replicated 3 × 3 Latin square design with 3 diets and 3 periods in each square. There were, therefore, 6 replicate pigs per treatment. Pigs were housed in individual pens equipped with a feeder and a nipple drinker in an environmentally controlled room. Pens had smooth sides and fully slatted tribar floors.

Two cornstarch-based diets were formulated using torula yeast or fish meal as the only AA-contributing ingredient in each diet and a N-free diet was used to determine basal endogenous losses of CP and AA (Table 2). Vitamins and minerals were included in all diets to meet or exceed current requirement estimates (NRC, 2012). All diets also contained 0.40% chromic oxide as an indigestible marker. Pigs were fed at 3 times the daily maintenance energy requirement (i.e., 197 kcal ME per $kg^{0.60}$; NRC, 2012). The daily allotment of feed was divided into 2 equal meals and provided at 0800 and 1600 h and water was available at all times.

The initial 5 d of each period were considered an adaptation period and ileal digesta were collected for 8 h on days 6 and 7. All samples were stored at –20 °C immediately after collection. At the end of each period, pigs were deprived of feed overnight, and a new experimental diet was offered the following morning.

At the conclusion of the experiment, ileal digesta samples were thawed, mixed within animal and diet, and a sub-sample was lyophilized and finely ground (Lagos and Stein, 2019). Samples of ileal digesta, diets, and ingredients were analyzed for CP (Method 990.03; AOAC Int., 2007) using a LECO FP 628 apparatus (LECO Corp., St. Joseph, MI), DM (Method 930.15; AOAC Int., 2007), and AA on a Hitachi AA Analyzer (Model No. L8800; Hitachi High Technologies America, Inc., Pleasanton, CA) using ninhydrin for postcolumn derivatization and norleucine as the internal standard [Method 982.30 E (a, b, c); AOAC Int., 2007]. Diets and ileal digesta samples were also analyzed for chromium (Method 990.08; AOAC Int., 2007).

Table 1. Analyzed composition of torula yeast and fish meal (as-fed basis)

Item	Torula yeast	Fish meal[1]
Gross energy, kcal/kg	4,590	4,307
DM, %	95.43	91.45
CP, %	51.68	64.77
Ash, %	12.56	19.61
Total Ca, %	0.13	5.10
Total P, %	1.78	3.35
Phytate, %	0.25	0.82
Phytate bound-P, %	0.07	0.23
Nonphytate P, %	1.74	3.10
Acid hydrolyzed ether extract, %	3.22	7.14
Total dietary fiber, %	20.5	4.00
Insoluble dietary fiber, %	4.10	4.00
Soluble dietary fiber, %	16.4	ND[2]
NDF, %	7.22	6.06
ADF, %	0.56	1.29
Indispensable AA, %		
Arg	2.39	3.60
His	0.91	1.17
Ile	2.31	2.55
Leu	3.42	4.22
Lys	3.45	4.51
Met	0.58	1.61
Phe	2.10	2.44
Thr	2.35	2.40
Trp	0.62	0.55
Val	2.79	2.94
Dispensable AA, %		
Ala	3.33	3.98
Asp	4.32	5.33
Cys	0.49	0.47
Glu	8.07	7.83
Gly	2.27	4.74
Pro	1.55	2.94
Ser	1.97	2.04
Tyr	1.67	1.68
Total AA, %	44.59	55.00
Lys: CP ratio	6.67	6.96

[1]The fish meal was a commercial source of menhaden fish meal (Omega Protein, Houston, TX).
[2]ND = nondetectable.

The apparent ileal digestibility (**AID**) of CP and AA was determined in the 2 diets containing torula yeast or fish meal (Stein et al., 2007). The basal endogenous losses of CP and AA were calculated from pigs fed the N-free diet, and these values were used to calculate SID of CP and AA in the diets containing torula yeast or fish meal (Stein et al., 2007). Values for AID and SID of CP and AA obtained for the diets also represented the AID and SID of CP and AA in torula yeast and fish meal because these ingredients were the only AA-containing ingredients in the diets. The concentration of standardized ileal digestible CP and AA in each ingredient was calculated by multiplying the concentration of CP and AA in each ingredient by the SID value for CP or AA in the ingredient (Cervantes-Pahm and Stein, 2008). Normality of residuals and assumptions of the model were tested using INFLUENCE, PROC GPLOT, and PROC UNIVARIATE

Table 2. Composition (as-is basis) of experimental diets containing torula yeast or fish meal, experiment 1

Item	Torula yeast	Fish meal	N-free
Ingredient, %			
Torula yeast	30.00	—	—
Fish meal	—	29.05	—
Lactose	20.00	20.00	20.00
Corn starch	46.45	50.00	67.90
Solca flok	—	—	4.00
Dicalcium phosphate	1.40	0.00	2.15
Limestone	1.20	0.00	0.50
Chromic oxide	0.40	0.40	0.40
Magnesium oxide	—	—	0.10
Potassium carbonate	—	—	0.40
Sodium chloride	0.40	0.4	0.40
Vitamin–micromineral premix[1]	0.15	0.15	0.15
Analyzed values, %			
DM	92.56	90.67	91.91
CP	16.02	18.72	0.37
Indispensable AA			
Arg	0.78	1.09	0.01
His	0.31	0.36	0.00
Ile	0.78	0.79	0.01
Leu	1.17	1.32	0.02
Lys	1.17	1.41	0.05
Met	0.20	0.52	0.01
Phe	0.71	0.75	0.01
Thr	0.80	0.74	0.01
Trp	0.20	0.18	0.02
Val	0.94	0.92	0.01
Dispensable AA			
Ala	1.13	1.22	0.02
Asp	1.48	1.67	0.02
Cys	0.17	0.17	0.00
Glu	2.84	2.50	0.06
Gly	0.74	1.46	0.02
Pro	0.55	0.92	0.05
Ser	0.66	0.62	0.01
Tyr	0.50	0.46	0.01
Total AA	15.13	17.10	0.34

[1]The vitamin–micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,150 IU; vitamin D_3 as cholecalciferol, 2,210 IU; vitamin E as selenium yeast, 66 IU; vitamin K as menadione nicotinamide bisulfate, 1.42 mg; thiamin as thiamine mononitrate, 1.10 mg; riboflavin,6.59 mg; pyridoxine as pyridoxine hydrochloride, 1.00 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.6 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper chloride; Fe, 125 mg as iron sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese hydroxychloride; Se, 0.30 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc hydroxychloride.

options of SAS (SAS Inst. Inc., Cary, NC). Data for the AID and SID of CP and AA as well as for the concentration of standardized ileal digestible CP and AA were analyzed using the PROC MIXED procedure of SAS. The model included diet as fixed effect and pig and period as random effects, with the experimental unit being the pig. Treatment means were calculated using LSMEANS and separated using the PDIFF statement of SAS. Statistical significance and tendency were considered at $P < 0.05$ and $0.05 \leq P < 0.10$, respectively.

Table 3. Composition (as-is basis) of experimental diets containing corn, torula yeast, or fish meal, experiment 2

Item	Corn	Torula yeast	Fish meal
Ingredient, %			
Ground corn	96.85	67.00	71.45
Torula yeast	—	30.6	—
Fish meal	—	—	28.00
Dicalcium phosphate	1.8	0.4	—
Ground limestone	0.80	1.45	—
Sodium cloride	0.40	0.40	0.40
Vitamin–micromineral premix[1]	0.15	0.15	0.15
Analyzed values			
GE, kcal/kg	3,921	3,962	3,751
DM, %	88.87	87.30	86.16

[1]The vitamin–micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,150 IU; vitamin D_3 as cholecalciferol, 2,210 IU; vitamin E as selenium yeast, 66 IU; vitamin K as menadione nicotinamide bisulfate, 1.42 mg; thiamin as thiamine mononitrate, 1.10 mg; riboflavin,6.59 mg; pyridoxine as pyridoxine hydrochloride, 1.00 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.6 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper chloride; Fe, 125 mg as iron sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese hydroxychloride; Se, 0.30 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc hydroxychloride.

Experiment 2: concentrations of DE and ME

Twenty-four weanling barrows (initial BW: 14.4 ± 1.1 kg) were allotted to a completely randomized design with 3 diets and 8 replicate pigs per diet. Pigs were placed in individual metabolism crates that were equipped with a self-feeder, a nipple waterer, and a slatted floor to allow for the total, but separate collection of urine and fecal materials. The 3 dietary treatments included a corn-based diet and 2 diets based on a mixture of corn and torula yeast or corn and fish meal (Table 3). Vitamins and minerals were included in all diets to meet or exceed the estimated nutrient requirements for weanling pigs (NRC, 2012). Pigs were limit fed at 3 times the energy requirement for maintenance (NRC, 2012), which was provided each day in 2 equal meals at 0800 and 1700 h. Throughout the study, pigs had ad libitum access to water. Feed consumption was recorded daily and diets were fed for 12 d. The initial 5 d were considered the adaptation period to the diet, whereas urine and fecal materials were collected from feed provided from days 6 to 9 using the marker-to-marker approach (Kong and Adeola, 2014). Urine was collected in buckets over a preservative of 50 mL of 3 *N* HCl. Fecal samples and 20% of the collected urine were stored at –20 °C immediately after collection.

At the conclusion of the experiment, urine samples were thawed and mixed within animal and diet, and a sub-sample was lyophilized before analysis (Kim et al., 2009). Fecal samples were thawed and mixed within pig and diet, and then dried at 65 °C in a forced air drying oven and ground through a 1-mm screen in a Wiley mill (Model 4; Thomas Scientific, Swedesboro, NJ) prior to analysis. Diet and fecal samples were analyzed for DM as described for experiment 1. Fecal, urine, diet, and ingredient samples were analyzed for GE using bomb calorimetry (Model 6400; Parr Instruments, Moline, IL). Ingredients were analyzed for acid-hydrolyzed ether extract (**AEE**; Method 2003.06, AOAC Int., 2007) using an Ankom^{HCl} apparatus (Ankom Technology, Macedon, NY)

for acid hydrolysis (3 N HCl) followed by crude fat extraction with ether extract using an Ankom^{XT15} apparatus (Ankom Technology). Insoluble and soluble dietary fiber (**SDF**) were also analyzed in the 2 ingredients according to method 991.43 (AOAC Int., 2007) using the Ankom^{TDF} Dietary Fiber Analyzer (Ankom Technology). Total dietary fiber (**TDF**) was then calculated as the sum of insoluble dietary fiber (**IDF**) and SDF. Ingredients were also analyzed for ADF and NDF using Ankom Technology methods 12 and 13, respectively (Ankom^{2000} Fiber Analyzer, Ankom Technology).

The apparent total tract digestibility (**ATTD**) of GE and DM and concentrations of DE and ME were calculated for each diet. The DE and ME of corn were calculated by dividing the DE and ME in the corn diet by the inclusion rate of corn in the diet. The contribution of DE and ME from corn to the DE and ME in the diets containing torula yeast or fish meal was then subtracted from the DE and ME of each diet, and the DE and ME of torula yeast and fish meal were calculated by difference (Kong and Adeola, 2014). The ATTD of GE and DM in torula yeast and fish meal was calculated using the same procedure.

Normality of residuals and assumptions of the model were tested as explained for experiment 1. Data were analyzed using the PROC MIXED function of SAS with the pig as the experimental unit. In the model, diet or ingredient was the fixed effect and pig and replicate were the random effects. Means calculation and significance consideration followed the procedures described for experiment 1.

Experiment 3: phosphorus digestibility

A total of 32 weanling barrows (initial BW: 11.9 ± 1.1 kg) were allotted to a completely randomized design with 4 diets and 8 replicate pigs per diet. Pigs were placed in metabolism crates as described for experiment 2 to allow for collection of feces. Four cornstarch-based diets were formulated based on torula yeast or fish meal (Table 4). Each ingredient was used in 2 diets containing either 0 or 1,000 units of microbial phytase (**FTU**; Quantum Blue; AB Vista Feed Ingredients, Marlborough, UK). Vitamins and minerals other than P were included in all diets to meet or exceed the estimated nutrient requirements for weanling pigs (NRC, 2012). The daily allotment of feed and water and the procedure for fecal collection and storage followed the protocol explained for experiment 2.

Fecal samples were thawed at the conclusion of the experiment and mixed within pig and diet, and dried at 65 °C in a forced air drying oven prior to analysis. Fecal, ingredient, and diet samples were analyzed for ash (Method 942.05; AOAC Int., 2007), and Ca and P were analyzed by inductively coupled plasma-optical emission spectrometry (Method 985.01 A, B, and D; AOAC Int., 2007) after wet ash sample preparation [Method 975.03 B(b); AOAC Int., 2007]. Dry matter in diets and fecal samples was analyzed as described for experiment 1. Ingredients were also analyzed for phytic acid (Ellis et al., 1977), and phytase activity (Phytex Method, Version 1; Eurofins, Des Moines, IA) was analyzed in diet samples.

The percentage of phytate-bound P in the ingredients was calculated by multiplying the analyzed concentration of phytate by 0.282 (Tran and Sauvant, 2004) and nonphytate P was calculated by subtracting the amount of phytate-bound P from total P. The ATTD of P in each ingredient and the ATTD of DM and Ca in diets were calculated (NRC, 2012). Values for the STTD of P in torula yeast and fish meal were calculated by correcting

Table 4. Composition of experimental diets containing torula yeast or fish meal (as-is basis), experiment 3

Item	No phytase		1,000 units of phytase	
Source of P:	Torula yeast	Fish meal	Torula yeast	Fish meal
Ingredient, %				
Torula yeast	39.35	—	39.35	—
Fish meal	—	29.50	—	29.50
Sucrose	8.00	8.00	8.00	8.00
Cornstarch	50.30	61.95	50.28	61.93
Ground limestone	1.80	—	1.80	—
Sodium chloride	0.40	0.40	0.40	0.40
Vitamin–mineral premix[1]	0.15	0.15	0.15	0.15
Phytase concentrate[2]	—	—	0.02	0.02
Analyzed values				
DM, %	93.41	91.26	93.17	90.96
Ash, %	6.97	6.33	7.16	6.40
Ca, %	0.53	1.62	0.53	1.75
P, %	0.68	0.95	0.77	0.93
Phytate[3], %	0.10	0.24	0.10	0.24
Phytate-bound P[4], %	0.03	0.07	0.03	0.07
Nonphytate P[4], %	0.65	0.88	0.74	0.86
Phytase activity, FTU[5]/kg	<70	<70	770	620

[1]The vitamin–micromineral premix provided the following quantities of vitamins and micro minerals per kilogram of complete diet: vitamin A as retinyl acetate, 11,150 IU; vitamin D_3 as cholecalciferol, 2,210 IU; vitamin E as DL-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 1.10 mg; riboflavin,6.59 mg; pyridoxine as pyridoxine hydrochloride, 1.00 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.6 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate; Fe, 125 mg as ironsulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganoussulfate; Se, 0.30 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.
[2]The phytase concentrate contained 5,000 units of phytase/g (Quantum Blue; AB Vista Feed Ingredients, Marlborough, UK).
[3]Phytate values in the diets were calculated from analyzed phytate in the ingredients.
[4]Phytate-bound P was calculated by multiplying the phytate by 0.282 (Tran and Sauvant, 2004). Nonphytate P was calculated as the difference between total P and phytate-bound P.
[5]FTU, phytase units.

the ATTD values for the basal endogenous loss of P (**EPL**; i.e., 190 mg/kg DMI; NRC, 2012).

Data were analyzed using the PROC MIXED of SAS with the experimental unit being the pig. The experimental model included the main effects of ingredient and phytase and the interaction between ingredient and phytase. Testing for normality of residuals and model assumptions, calculation of means, and consideration of significance followed procedures described for experiment 1.

Results

The AID and SID of CP and all AA in torula yeast were greater ($P < 0.05$) than in fish meal (Table 5). No differences in the concentration of standardized ileal digestible His and Leu were observed between the 2 ingredients, but fish meal had greater ($P < 0.05$) concentration of standardized ileal digestible Arg, Lys, Met, and Gly than torula yeast (Table 6). However, the concentration of standardized ileal digestible CP and all other AA was greater ($P < 0.05$) or tended ($P < 0.10$) to be greater in torula yeast than in fish meal.

There was no difference in the ATTD of GE among diets, but the ATTD of DM was greater ($P < 0.05$) in diets containing corn or corn and torula yeast than in the diet containing corn and fish meal (Table 7). However, the DE in the corn-yeast and corn-fish meal diets was greater ($P < 0.05$) than in the corn diet, and the concentration of ME tended ($P < 0.10$) to be greater in the corn-yeast and in the corn-fish meal diets than in the corn diet.

The ATTD of DM was greater ($P < 0.05$) in corn and torula yeast than in fish meal, but no differences in the ATTD of GE among ingredients were observed (Table 8). The DE (as-is basis) in torula yeast was greater ($P < 0.05$) than in fish meal, but there were no differences in the concentration of ME among the 3 ingredients. On a DM basis, no differences in DE among corn, torula yeast, and fish meal were observed, but ME was greater ($P < 0.05$) in corn than in fish meal or torula yeast.

There was no effect of ingredient on P intake of pigs, but pigs fed diets containing torula yeast had greater ($P < 0.05$) feed intake and DMI than pigs fed diets containing fish meal (Table 9). In contrast, fecal output, percentage of P in feces, and P output in feces were less ($P < 0.05$) from pigs fed diets containing torula yeast compared with pigs fed diets containing fish meal. The daily EPL was obtained by multiplying the amount of basal endogenous P secreted (190 mg/d; NRC, 2012) by the DMI (kg) of pigs, and was greater ($P < 0.05$) in pigs fed the torula yeast as the sole source of P than in pigs fed fish meal diets. However, the ATTD and STTD of P in torula yeast were greater ($P < 0.05$) than in fish meal. There were no effects of phytase on any response variables nor were any interactions between ingredients and phytase observed.

Calcium intake, percentage of Ca in feces, and Ca output in feces were greater ($P < 0.05$) in pigs fed diets containing fish meal compared with pigs fed diets containing torula yeast (Table 10). The ATTD of DM and Ca in diets containing torula yeast was greater ($P < 0.05$) than in diets containing fish meal. There was no effect of phytase on the response variables with the exception that diets with phytase tended ($P < 0.10$) to have

Table 5. AID and SID of CP and AA in torula yeast and fish meal (FM) fed to weanling pigs[1]

	AID				SID[2]			
	Ingredient				Ingredient			
Item, %	Torula yeast	FM	SEM	*P*-value	Torula yeast	FM	SEM	*P*-value
CP	85.3	61.7	1.59	<0.001	94.6	69.5	1.9	<0.001
Indispensable AA								
Arg	92.6	78.3	1.76	<0.001	99.4	83.0	1.76	<0.001
His	91.0	69.8	1.07	<0.001	96.3	74.3	1.07	<0.001
Ile	90.2	71.5	0.92	<0.001	93.9	75.0	0.92	<0.001
Leu	91.4	72.9	0.88	<0.001	95.3	76.3	0.88	<0.001
Lys	91.7	73.1	1.13	<0.001	95.2	76.0	1.13	<0.001
Met	90.3	74.8	0.99	<0.001	94.5	76.3	0.99	<0.001
Phe	90.6	69.8	0.91	<0.001	94.8	73.7	0.91	<0.001
Thr	78.8	65.6	1.13	<0.001	86.2	73.4	1.13	<0.001
Trp	92.1	79.0	0.91	<0.001	97.0	84.3	0.91	<0.001
Val	86.3	67.8	1.09	<0.001	92.4	73.9	1.09	<0.001
Mean	89.5	72.3	0.95	<0.001	94.5	76.6	0.95	<0.001
Dispensable AA								
Ala	90.0	71.7	1.23	<0.001	94.4	75.7	1.23	<0.001
Asp	87.2	57.6	0.96	<0.001	92.0	61.8	0.96	<0.001
Cys	74.6	55.4	1.53	<0.001	87.9	68.5	1.53	<0.001
Glu	92.1	72.2	0.72	<0.001	94.9	75.3	0.72	<0.001
Gly	79.3	66.2	3.39	0.008	99.5	76.2	3.39	<0.001
Ser	81.9	65.2	1.39	<0.001	89.2	72.8	1.39	<0.001
Tyr	89.8	67.7	0.95	<0.001	94.1	72.3	0.95	<0.001
Mean	85.0	65.1	1.33	<0.001	93.2	71.8	1.33	<0.001
All AA	87.6	69.3	1.10	<0.001	93.9	74.6	1.10	<0.001

[1]Data are least square means of 6 observations.
[2]Values for SID were calculated by correcting the values for AID for basal ileal endogenous losses ($n = 6$). Basal ileal endogenous losses were determined (g/kg DMI) as CP, 16.14; Arg, 0.57; His, 0.18; Ile, 0.31; Leu, 0.49; Lys, 0.45; Met, 0.09; Phe, 0.32; Thr, 0.64; Trp, 0.11; Val, 0.62; Ala, 0.54; Asp, 0.77; Cys, 0.25; Glu, 0.86; Gly, 1.61; Ser, 0.52; and Tyr, 0.23.

Table 6. Concentration of standardized ileal digestible CP and AA in torula yeast and fish meal fed to pigs[1]

Item, g/ kg	Torula yeast	Fish meal	SEM	P-value
CP	495.6	445.9	8.75	0.007
Indispensable AA				
Arg	23.7	29.9	0.48	<0.001
His	8.8	8.7	0.11	0.543
Ile	21.7	19.1	0.22	<0.001
Leu	32.6	32.2	0.33	0.297
Lys	32.9	34.3	0.44	0.005
Met	5.5	12.3	0.12	<0.001
Phe	19.9	18.0	0.21	<0.001
Thr	20.3	17.6	0.27	<0.001
Trp	6.0	4.6	0.05	<0.001
Val	25.8	21.7	0.31	<0.001
Total	197.7	199.1	2.17	0.567
Dispensable AA				
Ala	31.5	30.1	0.45	0.060
Asp	39.7	32.9	0.46	<0.001
Cys	4.3	3.2	0.07	<0.001
Glu	76.6	58.9	0.57	<0.001
Gly	22.6	36.1	0.90	<0.001
Ser	17.6	14.9	0.28	0.001
Tyr	15.7	12.1	0.16	<0.001
Total	206.1	187.2	3.09	0.005
All AA	404.3	388.6	5.05	0.048

[1]Data are least square means of 6 observations.

Table 7. ATTD of GE and DM and concentrations of DE and ME in diets containing corn, torula yeast, or fish meal, as-fed basis[1,2]

Item	Corn	Torula yeast	Fish meal	SEM	P-value
GE intake, kcal/d	2,894[b]	3,217[a]	3,248[a]	64.34	0.001
GE output in feces, kcal/d	311[b]	350[ab]	378[a]	18.78	0.016
GE output in urine, kcal/d	62[b]	140[a]	140[a]	7.54	<0.001
ATTD of GE, %	89.3	89.1	88.4	0.54	0.310
ATTD of DM, %	90.6[a]	90.3[a]	88.1[b]	0.50	0.001
DE, kcal/kg	3,349[b]	3,495[a]	3,504[a]	20.85	<0.001
ME, kcal/kg	3,265[y]	3,324[x]	3,332[x]	21.15	0.066

[1]Data are least square means of 8 observations.
[2]Values for daily intake or output are the average of a 4-d collection period.
[a,b]Means within a row lacking a common superscript letter are different ($P < 0.05$).
[x,y]Means within a row lacking a common superscript letter tend to be different ($P < 0.10$).

greater ATTD of Ca than diets without phytase. No interactions between ingredient and phytase were observed.

Discussion

The concentration of DM and CP torula yeast used in this experiment was close to values reported for torula yeast (NRC, 2012). However, concentrations of P and Lys, Trp, and Thr in torula yeast that was used in this experiment were slightly greater than values reported in the literature (NRC, 2012), and torula yeast had a greater concentration of DM, GE, CP, and ash than sources of torula yeast previously used in swine and poultry diets (Figueroa et al., 1990; Rodríguez et al., 2011). The main reason for these differences is likely that a lignocellulosic substrate was

Table 8. ATTD of DM and GE and concentrations of DE and ME in corn, torula yeast, and fish meal[1]

Item	Corn	Torula yeast	Fish meal	SEM	P-value
ATTD of DM, %	90.6[a]	90.0[a]	82.2[b]	1.28	<0.001
ATTD of GE, %	89.3	88.9	86.3	1.33	0.142
DE, kcal/kg	3,458[c]	3,850[a]	3,688[b]	54.47	<0.001
DE, kcal/kg DM	4,053	4,023	4,044	59.00	0.886
ME, kcal/kg	3,371	3,479	3,293	63.35	0.128
ME, kcal/kg DM	3,952[a]	3,636[b]	3,611[b]	68.16	0.005

[1]Data are least square means of 8 observations.
[a–c]Means within a row lacking a common superscript letter are different ($P < 0.05$).

used to grow the torula yeast used in the present experiment, which may contain different monosaccharides than substrates used to generate other sources of torula yeast. Brewers' yeast is commonly used for animal feeding and nutrient composition of brewers' yeast is usually comparable to that of dehulled soybean meal (Shurson, 2018). Torula yeast has greater concentration of GE, CP, Lys, Thr, Trp, ash, P, and NDF, but lower concentration of Ca, Met, ADF, and AEE than brewers' yeast (Sauvant et al., 2004; NRC, 2012; Kim et al., 2014; Rostagno et al., 2017). Between 20% and 30% of the yeast cell weight represents the bilayer cell wall, which is composed primarily of polysaccharides (Kogan and Kocher, 2007). The main polysaccharides in the cell wall of yeasts are mannoproteins (39%), β-1,3-glucans (51%), β-1,6-glucans (9%), and chitin (2%; Aguilar-Uscanga and François, 2003). The presence of these cell wall components is likely the reason the torula yeast used in this experiment was analyzed to contain ~20% TDF with the majority of that amount being SDF. The crude fiber concentration in torula yeast is only around 2% and ADF can be up to 3% (NRC, 2012). However, the TDF value includes the SDF, which is not included in ADF, and the majority of the TDF in the torula yeast used in this experiment is SDF, which is the reason for the much greater value for TDF than for crude fiber or ADF.

Fish meal is believed to be an excellent source of protein because of its balanced profile of AA, vitamins, and minerals, and fish meal is often used in diets for young pigs (Cho and Kim, 2011). However, the nutritional value of fish meal is highly variable due to differences in fish species, product freshness, and processing methods, which may result in differences in the growth performance of pigs (Kim and Easter, 2001; Jones et al., 2018). Concentrations of DM, GE, CP, AA, and AEE in the source of fish meal used in this experiment were within the range of previously reported values; however, concentrations of ash, Ca, and P were greater than published data (Sauvant et al., 2004; NRC, 2012; Kim et al., 2014; Rostagno et al., 2017). The concentration of whole body ash of a rainbow trout is 10.1% (Lee et al., 2001), and thus, the high concentration of ash in the fish meal used in this experiment indicates that a great proportion of fish bones, likely from the fish filet processing industry, was included in the final product. Concentrations of dietary fiber in fish meal have not been reported because ingredients from animal origin do not contain fiber, but in this experiment, values for TDF, IDF, NDF, and ADF in fish meal ranged from 1.29% to 6.06%. This observation may be a result of the fish species used because menhaden fish feeds not only on zooplankton, but also on phytoplankton (NOOA, 2017); therefore, fiber may be present in the stomach content of fish. It is also possible that the fiber analysis influences results. Nonfiber components such

Table 9. ATTD, DMI, EPL, and STTD of P in torula yeast and fish meal (FM) without and with microbial phytase[1,2]

Item	No phytase		1,000 phytase units			*P*-value		
Ingredient	Torula yeast	FM	Torula yeast	FM	SEM	Ingredient	Phytase	Ingredient × phytase
Feed intake, g/d	625	529	585	508	33.85	0.016	0.368	0.786
DMI, g/d	584	483	545	462	31.25	0.007	0.342	0.779
P intake, g/d	4.26	5.01	4.51	4.71	0.28	0.102	0.917	0.331
Fecal output, g/d	21.7	34.8	18.9	28.4	3.08	0.001	0.149	0.557
P in feces, %	2.22	4.97	2.24	5.11	0.24	<0.001	0.741	0.792
P in feces, g/d	0.48	1.76	0.42	1.50	0.18	<0.001	0.384	0.602
ATTD of P, %	88.6	66.2	90.7	68.8	2.58	<0.001	0.372	0.924
EPL[3], mg/d	111.0	91.8	103.6	87.8	5.94	0.007	0.342	0.779
STTD of P[4], %	91.2	68.0	93.0	70.7	2.58	<0.001	0.400	0.873

[1]Data are least square means of 8 observations.
[2]Values for daily intake or output are the average of a 4-d collection period.
[3]Calculated by multiplying the EPL (190 mg/kg DMI; NRC, 2012) by the daily DMI.
[4]Values for STTD were calculated by correcting ATTD values by the EPL.

Table 10. Effect of addition of 1,000 units of phytase (**FTU**) on ATTD of DM and Ca in torula yeast or fish meal (FM)[1,2]

Item	No phytase		1,000 FTU			*P*-value		
Ingredient	Torula yeast	FM	Torula yeast	FM	SEM	Ingredient	Phytase	Ingredient × phytase
Ca intake, g/d	3.31	8.58	3.09	8.89	0.41	<0.001	0.919	0.517
Ca in feces, %	3.44	8.79	2.58	9.11	0.56	<0.001	0.631	0.305
Ca in feces, g/d	0.79	3.11	0.48	2.69	0.35	<0.001	0.299	0.873
ATTD of DM, %	96.5	93.1	96.8	94.0	0.39	<0.001	0.149	0.473
ATTD of Ca, %	76.8	65.1	84.2	70.5	3.70	0.002	0.093	0.791

[1]Data are least square means of 8 observations.
[2]Values for daily intake or output are the average of a 4-d collection period.

as bone-surrounding cartilage in fish meal may have been analyzed as fiber. Proteoglycans are the second most abundant components in articular cartilage and are also present in plant cell walls and in dietary fiber analysis, proteoglycans are analyzed as insoluble fiber (Selvendran and Verne, 1990; Sophia Fox et al., 2009), which likely further contributed to the analyzed concentrations of fiber in fish meal. The observation that fish meal contains 0.82% phytate is in agreement with data from Kim et al. (2014) that reported a content of 0.33% of phytate in menhaden fish meal. Although phytate is not expected to be present in fish meal, the fact that in both experiments menhaden fish meal sources were used indicates that phytate is likely coming from the stomach content of the fish.

The concentration of CP and most AA in fish meal was greater than in torula yeast, but the concentration of Trp was greater in torula yeast than in fish meal, which is important because Trp is often limited in diets for pigs (NRC, 2012). Although values for the AID and SID of AA in fish meal were in agreement with values reported by Kim and Easter (2001), greater values have also been reported (Sauvant et al., 2004; NRC, 2012; Rostagno et al., 2017). The low digestibility values for AA in fish meal obtained in this experiment may be due to the likely presence of a high proportion of bone in the fish meal as indicated by the high ash concentration because the main protein in bone is collagen, which has a low digestibility of AA (Garcia and Phillips, 2009).

The AID and SID of CP and AA in torula yeast were greater than published values for single-cell proteins (Wang et al., 2013; Zhang et al., 2013), brewers' yeast (Sauvant et al., 2004; NRC, 2012; Rostagno et al., 2017), and yeast extract (Mateo and Stein, 2007). This may indicate that torula yeast used in this experiment is different from other yeast sources that are currently used in the feed industry. Indeed, values for the digestibility of AA in torula yeast are comparable with values reported for whey protein concentrate fed to growing pigs (Gottlob et al., 2006). The reason for the high AID and SID in this source of torula yeast is likely due to the specific strain of yeast that was used. This strain is engineered to grow on the monosaccharides that are released from the lignocellulosic material that was used as substrate and the torula yeast used in this experiment, therefore, differs from other sources of torula yeast. This may have resulted in a different source of protein being generated.

Values for DE and ME in corn obtained in this experiment are in close agreement with values reported in the literature (NRC, 2012; Stein et al., 2016; Rostagno et al., 2017), which gives confidence that the values calculated for fish meal and torula yeast are correct. The fish meal used in this experiment had DE and ME that were less than reported by NRC (2012) and Rojas et al. (2014), but greater than published by Rojas and Stein (2013) and Rostagno et al. (2017), which further demonstrates the nutritional variability among sources of fish meal. Values for DE and ME in the torula yeast used in this study were less than values reported for torula yeast, brewer's yeast, and ethanol yeast, that range from 4,015 to 4,461 kcal/kg and from 3,530 to 4,016 kcal/kg for DE and ME, respectively (NRC, 2012; Kim et al., 2014). The reason for this observation is likely that the yeast used in this experiment contained more ash and less AEE than the yeast used in previous experiments. Nevertheless, the observation that the DE and ME in torula yeast were not different form values in fish meal indicates that if torula yeast

is used instead of fish meal, there will not be a reduction in the concentration of ME in the diet.

The STTD of P in torula yeast was greater than published values for ethanol and brewer's yeasts ranging from 70.0% to 85.2% (NRC, 2012; Kim et al., 2014). This is likely because the concentration of phytate bound-P in the torula yeast used in this experiment is low compared with that in other sources of yeast. The observation that the daily EPL from pigs fed torula yeast was greater than from pigs fed fish meal is a result of the greater DM intake of pigs fed diets containing torula yeast compared with pigs fed diets containing fish meal, and the quantity of EPL is related to the intake of DM. Because the intake of P by pigs was not different between the 2 ingredients, but fecal output from pigs fed fish meal was greater than that from pigs fed torula yeast, values for the ATTD and STTD of P in the torula yeast were greater than values for fish meal.

The STTD of P in fish meal obtained in this experiment was less than values reported by NRC (2012) and Rostagno et al. (2017), but in agreement with values obtained in other studies (Kim et al., 2014; Rojas et al., 2014). Phosphorus in bone tissue is less digestible than P in soft tissue (Sulabo and Stein, 2013) and the low STTD of P obtained in this experiment is, therefore, likely a consequence of the high concentration of fish bones in the fish meal as indicated by the high ash concentration. The concentration of ash in the fish meal used in this experiment was close to that reported by Kim et al. (2014) and Rojas et al. (2014) who also reported low STTD values for P in fish meal.

The lack of effects of microbial phytase on the STTD of P in both torula yeast and fish meal is likely a result of the low concentrations of phytate in these ingredients. However, the tendency for an increased ATTD of Ca in fish meal and in torula yeast by the inclusion of phytase is in agreement with published data (González-Vega et al., 2015) and supports the hypothesis that the stomach content of menhaden fish may have contained phytate from phytoplankton. These observations indicate that Ca from fish meal and torula yeast binds to the phytate in the diets, but if phytase is added some of the phytate-bound Ca is released. The ATTD of Ca in fish meal obtained in this experiment was greater than previously reported (González-Vega et al., 2015), but close to data available for fish bones fed to pigs (Malde et al., 2010). The ATTD of Ca in the 2 diets containing torula yeast mostly represents the digestibility of Ca in limestone because the other ingredients in the diet did not provide much Ca. It is, therefore, not surprising that the ATTD of Ca that was obtained for the torula yeast diet without phytase (i.e., 76.8%) is close to the ATTD of Ca in limestone (74.3%) reported by Merriman and Stein, (2016).

Conclusions

Results of these experiments indicate that the torula yeast that was used in this work has a greater SID of AA and STTD of P than the source of Menhaden fish meal used in this experiment. However, the concentration of ME was not different between torula yeast and the source of fish meal used. Therefore, it is likely that torula yeast can be included in diets for weanling pigs at the expense of fish meal as long as the differences in the concentration of standardized ileal digestible AA between the 2 ingredients are taken into consideration during diet formulation.

Acknowledgements

Funding for this research by Arbiom Inc., Raleigh, NC, is greatly appreciated.

Conflict of interest statement

None declared.

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