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Standardized total tract digestibility of phosphorus in bakery meal fed to pigs and effects of bakery meal on growth performance of weanling pigs

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ABSTRACT

Two experiments were conducted to test the hypotheses that microbial phytase improves the standardized total tract digestibility (STTD) of phosphorus (P) in bakery meal and that corn may be replaced by bakery meal in diets for weanling pigs without negative effects on growth performance. Two sources of bakery meal were used in experiment 1 and one of these sources was also used in experiment 2. In experiment 1, eighty weanling barrows (initial body weight: 14.25 ± 1.91 kg) were allotted to a randomized complete block design with 10 diets and 8 replicate pigs per diet. Two basal diets based on each source of bakery meal (i.e., bakery meal 1 and bakery meal 2) were formulated without addition of microbial phytase. Eight additional diets were formulated by adding 500, 1000, 1500, or 3000 units of microbial phytase to each of the 2 basal diets. Pigs were housed individually in metabolism crates and feces were collected quantitatively for 4 d after 5 d of adaptation. Results indicated that greater increases in apparent total tract digestibility and STTD of P were observed in bakery meal 1 compared with bakery meal 2 when phytase was added to diets (interaction, quadratic, $P < 0.05$). In the second experiment, 160 newly weaned pigs (initial body weight: 7.17 ± 0.94 kg) were randomly allotted to 5 treatments with 8 pens per treatment and 4 pigs per pen. A 2-phase feeding program was used with d 1–14 being phase 1 and d 15–35 being phase 2. A control diet, containing primarily corn, soybean meal, and no bakery meal was formulated in each phase. Four additional diets in each phase were formulated by replacing 250, 500, 750, or 1000 g/kg of corn in the control diet with bakery meal. Results indicated that for the overall 5-wk nursery period, increasing concentrations of bakery meal tended (linear, $P = 0.064$) to reduce average daily gain and reduced (linear, $P < 0.01$) gain to feed ratio of pigs, whereas blood indicators of energy and protein utilization were not affected. In conclusion, digestible P in bakery meal may be increased by including microbial phytase in the diets, but a full replacement of corn with bakery meal in diets for weanling pigs may reduce growth performance.

Abbreviations: AA, amino acids; ADFI, average daily feed intake; ADG, average daily gain; ATTD, apparent total tract digestibility; BUN, blood urea nitrogen; CP, crude protein; EPL, endogenous phosphorus loss; G:F, gain to feed ratio; FTU, phytase units; P, phosphorus; STTD, standardized total tract digestibility.

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1. Introduction

Approximately one-third of all food produced in the world is lost or wasted before being consumed by humans (Kummu et al., 2012), but some of this wasted food may be re-used in diets for animals (Jinno et al., 2018; Shurson, 2020). The large use of grains in the feeding of livestock may not be sustainable due to the growth in global population and competition between the production of food and feed (Pinotti et al., 2021). However, if more food-based coproducts can be recycled as animal feed, the usage of grain can be reduced, and the negative impact of un-consumed food on the environment may be reduced (Jinno et al., 2018).

Food leftovers such as bakery meal are produced by collecting and mixing unconsumed human foods and consists of a mixture of bread, breakfast cereals, cookies, and other foods that were not used for their intended purpose (Slominski et al., 2004; Liu et al., 2018; Pinotti et al., 2019; Luciano et al., 2020). The collected food products are sorted, unpacked, ground, sieved, and sometimes dried to create feed ingredients that may replace cereal grains in the feeding of animals (Ottoboni et al., 2019). More than 500,000 tons of bakery meal is produced annually in the United States (Liu et al., 2018), whereas about 90,000 tons of ex-food (also termed former foodstuff) are processed in the EU (Luciano et al., 2020). In both cases, however, these quantities represent only a limited part of all wasted human food (Jinno et al., 2018) indicating that more of these ingredients may be used in animal feeding in the future.

One of the challenges with using bakery meal in animal feeding is that chemical and nutritional composition may vary depending on the raw materials that are available for production (Slominski et al., 2004). However, results of a recent survey of the nutritional

Table 1
Analyzed nutrient composition of 2 sources of bakery meal.

Item	Bakery meal 1	Bakery meal 2
Dry matter, g/kg	822.0	848.0
Gross energy, MJ/kg	16.5	16.8
Crude protein, g/kg	96.1	152.6
Ash, g/kg	32.9	39.8
Starch, g/kg	451.0	382.0
Acid-hydrolyzed ether extract, g/kg	58.7	25.1
Soluble dietary fiber, g/kg	17.0	4.0
Insoluble dietary fiber, g/kg	91.0	97.0
Total dietary fiber, g/kg	108.0	101.0
Ca, g/kg	2.4	7.3
Total P, g/kg	1.6	2.7
Phytic acid, g/kg	< 1.4	5.1
Phytate-bound P[a], g/kg	< 0.4	1.4
Non-phytate P[b], g/kg	1.2	1.3
Cl, g/kg	13.0	9.0
K, g/kg	3.0	2.5
Mg, g/kg	0.4	0.9
Na, g/kg	8.1	5.9
S, g/kg	1.6	2.9
Mn, mg/kg	8.48	8.46
Cu, mg/kg	14.92	13.19
Zn, mg/kg	20.67	44.49
Fe, mg/kg	61.84	70.27
Indispensable amino acids, g/kg		
Arg	4.3	8.1
His	2.0	3.7
Ile	4.8	6.7
Leu	8.3	13.8
Lys	3.5	5.9
Met	1.4	2.5
Phe	6.0	8.0
Thr	3.6	5.8
Trp	1.2	1.4
Val	5.6	9.0
Total	40.7	64.9
Dispensable amino acids, g/kg		
Ala	4.7	9.1
Asp	6.6	10.7
Cys	2.2	2.6
Glu	16.9	22.4
Gly	4.0	7.1
Pro	6.1	8.7
Ser	3.9	6.2
Tyr	9.8	10.6
Total	54.2	77.4
All AA	94.9	142.3

[a] Calculated as 282 g/kg of phytic acid (Tran and Sauvant, 2004).
[b] Calculated as total P minus phytate-bound P.

composition of bakery meal sold in the United States indicated that bakery meals sold in the United States have a consistent composition regardless of where in the country it is produced (Liu et al., 2018). It therefore appears that producers of bakery meal are able to blend different product streams to produce a final product with a constant nutrient profile.

The digestibility of CP and amino acids (AA) in bakery meal has been reported (Almeida et al., 2011; Casas et al., 2015, 2018) and data for digestible energy, metabolizable energy, and the standardized total tract digestibility (STTD) of phosphorus (P) in bakery meal are also available (Rojas et al., 2013; Luciano et al., 2020). Most P in plant-based feed ingredients is bound to phytate, but pigs and poultry do not synthesize adequate amounts of endogenous phytase to liberate the P in phytate; therefore, P digestibility in plant ingredients is relatively low when fed to pigs (Liao et al., 2005). Use of microbial phytase in diets for pigs improves P absorption and utilization by hydrolyzing phytate within the gastrointestinal tract of pigs (Pallauf et al., 1994). However, to our knowledge, data for effects of increasing levels of microbial phytase on STTD of P in bakery meal have not been reported.

Although data on growth performance of weanling pigs fed diets containing 300 g/kg bakery meal have been reported (Tretola et al., 2019a, 2019b), data for greater inclusion of bakery meal in diets for weanling pigs are not available. Due to differences in nutrient composition between bakery meal and corn, protein utilization of pigs fed diets containing bakery meal instead of corn may be different, but data to demonstrate this are limited. Therefore, the objectives of this work were to test the hypotheses that inclusion of graded levels of microbial phytase in diets based on bakery meal improves the STTD of P and that replacing corn with bakery meal will not influence growth performance of weanling pigs if diets are balanced for digestible nutrients.

2. Materials and methods

Protocols for 2 experiments were reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois Urbana-Champaign. Pigs that were the offspring of Line 359 boars mated to Camborough females (Pig Improvement Company, Hendersonville, TN, USA) were used in both experiments. Two sources of bakery meal (bakery meal 1 and bakery meal 2; Quincy Farm Products; Quincy, IL, USA) were used (Table 1).

2.1. Animals, treatments, and experimental procedure

2.1.1. Experiment 1: phosphorus digestibility

Eighty barrows (initial body weight: 14.25 ± 1.91 kg) were allotted to a randomized complete block design with 2 blocks, 10 diets, 4 pigs per diet in each block for a total of 8 replicate pigs per diet. Pigs were weaned 2 weeks apart and weaning group was used as the blocking factor. Two basal diets based on each source of bakery meal without microbial phytase were formulated (Tables 2 and 3). Eight additional diets that were similar to the 2 basal diets were formulated with the exception that 500, 1000, 1500, or 3000 units of microbial phytase (Quantum Blue 5 G, AB Vista, Marlborough, UK) were added to each diet. Other than P, vitamins and minerals were included in all diets to meet or exceed the estimated nutrient requirements for weanling pigs (NRC, 2012).

Pigs were housed individually in metabolism crates that were equipped with a self-feeder, a nipple waterer, a slatted floor, and a screen under the slatted floor that allowed for total collection of feces. Pigs were fed 3.2 times the metabolizable energy requirement for maintenance (i.e., 0.824 MJ per kg body weight$^{0.60}$; NRC, 2012), which was provided each day in 2 equal meals at 0730 and 1530 h. Throughout the experiment, pigs had free access to water. Feed consumption was recorded daily and diets were fed for 12 days. The initial 5 days were considered the adaptation period to the diet, whereas feces were collected during the following 4 days according to standard procedures using the marker-to-marker approach (Adeola, 2001). Chromic oxide (at approximately 3 g/kg) was used as the marker. Fecal samples were stored at −20 °C immediately after collection.

Table 2
Ingredient composition of experimental diets, as-fed basis, experiment 1.[a]

	FTU[b]/kg				
Item, g/kg	0	500	1000	1500	3000
Bakery meal	984.9	984.9	984.9	984.9	984.9
Cornstarch	0.6	0.5	0.4	0.3	–
Calcium carbonate	9.0	9.0	9.0	9.0	9.0
Salt	4.0	4.0	4.0	4.0	4.0
Phytase concentrate[c]	–	0.1	0.2	0.3	0.6
Vitamin-mineral premix[d]	1.5	1.5	1.5	1.5	1.5

[a] Two sources of bakery meal were used for a total of 10 experimental diets.
[b] FTU = phytase units.
[c] The phytase concentrate (Quantum Blue 5000; AB Vista, Marlborough, UK) contained 5000 FTU per gram. At 0.1 g/kg, 0.2 g/kg, 0.3 g/kg, and 0.6 g/kg inclusion, the concentrate provided 500, 1000, 1500, and 3000 units of phytase per kg of complete diet, respectively.
[d] 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, 2210 IU; vitamin E as DL-alpha tocopheryl acetate, 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.

Table 3
Analyzed composition of diets, as-fed basis, experiment 1.

	FTU/kg[a]				
Item	0	500	1000	1500	3000
Bakery meal 1					
Dry matter, g/kg	825.6	820.3	820.3	828.9	824.5
Ash, g/kg	47.5	44.0	44.7	44.4	43.4
Ca, g/kg	5.8	5.7	6.4	7.2	6.0
P, g/kg	1.3	1.2	1.2	1.2	1.3
Phytase, FTU/kg	84	480	1100	1500	3000
Bakery meal 2					
Dry matter, g/kg	848.0	850.3	845.8	846.9	847.8
Ash, g/kg	47.6	48.6	51.8	53.3	54.4
Ca, g/kg	8.8	9.5	10.2	11.2	10.9
P, g/kg	3.0	3.0	3.1	3.2	3.1
Phytase, FTU/kg	< 70	470	910	1500	3200

[a] FTU = phytase units.

Table 4
Composition of phase 1 experimental diets, experiment 2.

	Corn replacement rate, g/kg				
Item	0	250	500	750	1000
Ingredient, g/kg					
Corn	520.0	391.4	264.0	137.6	–
Bakery meal	–	129.4	257.7	385.1	523.4
Soybean meal, 48% CP	195.0	195.0	195.0	195.0	195.0
Whey powder	150.0	150.0	150.0	150.0	150.0
Fish meal	50.0	50.0	50.0	50.0	50.0
Spray dried protein plasma	35.0	35.0	35.0	35.0	35.0
Choice white grease	25.4	25.4	25.4	25.4	25.4
Limestone	10.3	10.0	9.5	9.3	8.6
Dicalcium phosphate	2.0	1.5	1.0	–	–
L-Lys HCl, 78%	3.5	3.5	3.5	3.6	3.6
DL-Met, 98%	1.4	1.5	1.6	1.7	1.7
L-Thr, 99%	0.9	0.8	0.8	0.8	0.8
Sodium chloride	5.0	5.0	5.0	5.0	5.0
Vitamin-mineral premix[a]	1.5	1.5	1.5	1.5	1.5
Analyzed values					
Dry matter, g/kg	878.5	873.1	872.7	862.9	859.6
Ash, g/kg	55.7	56.1	58.7	60.7	65.5
Gross energy, MJ/kg	16.8	16.9	17.0	17.2	17.3
Crude protein, g/kg	212.4	210.5	220.3	225.5	230.6
Acid-hydrolyzed ether extract, g/kg	56.7	62.8	69.3	70.7	80.0
Ca, g/kg	9.2	9.8	9.3	9.1	9.6
P, g/kg	6.7	6.3	6.1	6.0	5.8
Amino acids, g/kg					
Arg	11.7	12.4	12.9	12.6	12.8
His	5.3	5.5	5.6	5.4	5.4
Ile	9.1	9.6	10.1	10.0	10.5
Leu	17.9	18.3	18.8	17.9	18.4
Lys	16.0	16.3	17.0	16.5	17.0
Met	4.6	4.7	5.2	5.1	4.8
Met + Cys	8.2	8.4	9.2	9.0	8.6
Phe	9.7	10.3	10.9	10.7	11.3
Thr	9.8	9.9	10.4	10.2	10.5
Trp	2.9	2.8	3.0	3.1	3.2
Val	10.8	11.3	12.0	11.7	12.4
Lys:Metabolizable energy[b]	4.11	4.11	4.11	4.11	4.11

[a] Provided the following quantities of vitamins and micro-minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D_3 as cholecalciferol, 2208 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 chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese hydroxychloride; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc hydroxychloride.

[b] Calculated as standardized ileal digestible Lys to metabolizable energy ratio.

2.1.2. Experiment 2: growth performance

A total of 160 newly weaned pigs (initial body weight: 7.17 ± 0.94 kg) were allotted to 1 of 5 dietary treatments in a randomized complete block design with body weight as the block. A 2-phase feeding program was used with day 1–14 as phase 1 and day 15–35 as phase 2. There were 4 pigs per pen and 8 replicate pens per treatment. A total of 10 diets were formulated (Tables 4 and 5), and all diets in phases 1 and 2 were formulated to meet nutrient requirements for weanling pigs (NRC, 2012). In each phase, a control diet containing primarily corn and soybean meal and no bakery meal was formulated, and within each phase, 4 additional diets were formulated by replacing 250, 500, 750, or 1000 g/kg of the corn in the control diet with bakery meal (bakery meal 1; Quincy Farm Products; Quincy, IL, USA). All diets were calculated to have a similar standardized ileal digestible Lys to metabolizable energy ratio.

Individual pig weights were recorded at the beginning of the experiment, on day 14, and on day 35. Feed additions were recorded daily and the weight of feed left in the feeder was recorded on day 14 and 35. Diarrhea scores were assessed visually per pen every other day using a score from 1 to 5 (1 = normal feces; 2 = moist feces; 3 = mild diarrhea; 4 = severe diarrhea; and 5 = watery diarrhea). Diarrhea frequency was obtained by totaling the number of pen days with diarrhea scores greater than or equal to 3 divided by the total number of pen days multiplied by 100, with pen days referring to the number of pens multiplied by the number of days assessing diarrhea scores. At the end of each phase, a blood sample was collected from one pig per pen via vena puncture. Samples were collected in vacutainers with heparin to yield blood plasma and these samples were stored at −20 °C until analyzed.

2.2. Sample analyses

2.2.1. Experiment 1: phosphorus digestibility

At the conclusion of the experiment, fecal samples were thawed and mixed within pig and diet, and then dried at 50 °C in a forced

Table 5
Composition of phase 2 experimental diets, experiment 2.

	Corn replacement rate, g/kg				
Item	0	250	500	750	1000
Ingredient, g/kg					
Corn	542.1	406.9	271.9	135.8	–
Bakery meal	–	135.5	271.1	407.6	543.5
Soybean meal, 48% CP	305.0	305.0	305.0	305.0	305.0
Whey powder	100.0	100.0	100.0	100.0	100.0
Choice white grease	22.0	22.0	22.0	22.0	22.0
Limestone	9.5	9.5	9.2	9.0	8.8
Dicalcium phosphate	8.6	8.3	8.0	7.8	7.8
L-Lys HCl, 78%	3.8	3.8	3.8	3.8	3.8
DL-Met, 98%	1.5	1.5	1.5	1.6	1.7
L-Thr, 99%	1.0	1.0	1.0	0.9	0.9
Sodium chloride	5.0	5.0	5.0	5.0	5.0
Vitamin-mineral premix[a]	1.5	1.5	1.5	1.5	1.5
Analyzed values					
Dry matter, g/kg	877.5	872.7	864.7	860.5	853.6
Ash, g/kg	51.0	51.0	53.9	53.2	61.0
Gross energy, MJ/kg	16.5	16.7	16.8	16.8	17.0
Crude protein, g/kg	200.9	205.9	202.8	213.3	219.9
Acid-hydrolyzed ether extract, g/kg	54.0	54.5	58.9	63.2	68.5
Ca, g/kg	7.5	7.7	7.8	8.0	8.2
P, g/kg	6.0	6.0	6.0	6.0	6.1
Amino acids, g/kg					
Arg	12.8	13.0	13.3	13.5	13.8
His	5.4	5.8	6.1	6.5	6.8
Ile	8.7	8.9	9.1	9.3	9.6
Leu	17.4	17.2	17.1	17.0	16.9
Lys	14.2	14.4	14.6	14.8	15.0
Met	4.6	4.6	4.6	4.7	4.8
Met + Cys	7.1	7.1	7.1	7.1	7.1
Phe	9.8	9.9	10.1	10.2	10.4
Thr	8.9	9.0	9.2	9.2	9.3
Trp	2.5	2.6	2.7	2.8	2.9
Val	9.5	9.6	9.8	10.0	10.2
Lys:Metabolizable energy[b]	3.82	3.82	3.82	3.82	3.82

[a] Provided the following quantities of vitamins and micro-minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin D_3 as cholecalciferol, 2208 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 chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese hydroxychloride; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc hydroxychloride.

[b] Calculated as standardized ileal digestible Lys to metabolizable energy ratio.

air-drying oven and ground through a 1-mm screen in a Wiley mill (Model 4, Thomas Scientific, Swedesboro, NJ, USA). After wet ash sample preparation (Method 975.03; AOAC International, 2007), fecal samples, ingredients, and diets were analyzed for P by inductively coupled plasma spectroscopy (Method 985.01; AOAC International, 2007) and for dry matter by oven drying at 135 °C for 2 h (Method 930.15; AOAC International, 2007). Diets and ingredients were also analyzed for Ca and ash (Method 942.05; AOAC International, 2007), and the 2 sources of bakery meal were analyzed for insoluble dietary fiber and soluble dietary fiber (Method 991.43; AOAC International, 2007) using the ANKOM^{TDF} Dietary Fiber Analyzer (Ankom Technology, Macedon, NY, USA). Total dietary fiber was calculated as the sum of IDF and SDF. Nitrogen was also analyzed in ingredients using the combustion procedure (Method 990.03; AOAC International, 2007) on an FP628 protein analyzer (Leco Corporation, St. Joseph, MI, USA). Aspartic acid was used as a calibration standard and crude protein was calculated as the concentration of analyzed nitrogen multiplied by 6.25. Ingredients were analyzed for phytic acid (Ellis et al., 1977), and all diets were analyzed for phytase activity (Method 2000.12; AOAC International, 2007; Eurofins Scientific Inc., Des Moines, IA, USA). Using benzoic acid as internal standard, ingredient samples were analyzed for gross energy using an isoperibol bomb calorimeter (Model 6400, Parr Instruments, Moline, IL, USA), and AA were analyzed on a Hitachi Amino Acid Analyzer (Model L8880, Hotachi High Tecnologies America Inc., Pleasanton, CA, USA). The concentration of acid-hydrolyzed ether extract in ingredients was determined by acid hydrolysis using 3*N* HCl (Sanderson, 1986) followed by crude fat extraction with petroleum ether (method 2003.06, AOAC International, 2007). Bakery meal samples were also analyzed for Mg, Cu, Fe, Mn, and Zn as explained for the analysis of P, for Na and K using flame emission photometry (Hald and Mason, 1958), for Cl using manual titration (Gilliam, 1971), and for S using a gravimetric method (Wu and Mousavi, 2017).

2.2.2. Experiment 2: growth performance

All diet samples were ground through a 1-mm screen in a Wiley mill (Model 4, Thomas Scientific, Swedesboro, NJ, USA) prior to chemical analysis. Diets were analyzed for dry matter, ash, gross energy, CP, AA, Ca, and P as indicated for experiment 1. Blood samples were analyzed for blood urea nitrogen (BUN), total protein, and albumin using a Beckman Coulter Clinical Chemistry AU analyzer (Beckman Coulter, Inc., Brea, CA, USA).

2.3. Calculation and statistical analyses

2.3.1. Experiment 1: phosphorus digestibility

The apparent total tract digestibility (ATTD) of P in each diet was calculated (NRC, 2012) by subtracting the amount of P output in feces from P intake and this was then divided by P intake. By correcting values for ATTD of P in each diet for the basal endogenous losses of P (i.e., 190 mg per kg dry matter intake; NRC, 2012), the STTD of P in each diet was calculated. Because bakery meal was the only source of P in the diets, values for ATTD and STTD of P in each diet also represented the ATTD and STTD of P in the 2 sources of bakery meal that were used in the experiment.

Table 6
Coefficients of apparent total tract digestibility (ATTD), and standardized total tract digestibility (STTD) of P in 2 sources of bakery meal fed to growing pigs, experiment 1.[a]

Item	ADFI, g/d	P intake, g/d	P in feces, g/kg	P output, g/d	P absorption, g/d	ATTD of P	Basal EPL[b], mg/d	STTD of P[c]
Bakery meal 1								
0 FTU[d]/kg	758	1.21	4.65	0.38	0.84	0.688	120	0.787
500 FTU/kg	756	1.21	3.75	0.31	0.90	0.744	118	0.841
1000 FTU/kg	763	1.20	3.58	0.29	0.89	0.742	119	0.839
1500 FTU/kg	806	1.29	3.38	0.31	0.98	0.765	134	0.869
3000 FTU/kg	801	1.28	3.62	0.32	0.96	0.746	134	0.851
Bakery meal 2								
0 FTU/kg	758	2.05	9.13	0.98	1.06	0.520	122	0.580
500 FTU/kg	730	1.96	6.06	0.64	1.32	0.670	118	0.730
1000 FTU/kg	731	1.98	5.95	0.71	1.26	0.652	117	0.711
1500 FTU/kg	755	2.04	5.24	0.56	1.48	0.723	122	0.783
3000 FTU/kg	746	2.03	5.23	0.62	1.46	0.696	120	0.756
SEM	50.0	0.106	0.214	0.042	0.114	0.026	8.0	0.026
P-values								
Bakery meal	0.092	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.073	< 0.001
Phytase, Linear	0.268	0.487	< 0.001	< 0.001	< 0.001	< 0.001	0.035	< 0.001
Phytase, Quadratic	0.905	0.920	< 0.001	< 0.001	0.014	< 0.001	0.947	< 0.001
Bakery meal × Phytase, Linear	0.303	0.437	< 0.001	< 0.001	0.031	0.009	0.038	0.016
Bakery meal × Phytase, Quadratic	0.728	0.769	< 0.001	< 0.001	0.019	0.043	0.662	0.042

[a] Data are least squares means of 6–8 observations per treatment.
[b] EPL = endogenous P loss. This value was estimated to be at 190 mg/kg dry matter intake. The daily basal endogenous P loss (mg/d) for each diet was calculated by multiplying the endogenous P loss (mg/kg dry matter intake) by the daily dry matter intake of each diet (Almeida and Stein, 2010).
[c] Values for STTD were calculated by correcting values for ATTD for basal endogenous losses (NRC, 2012).
[d] FTU = phytase units.

Data were analyzed using the Mixed Procedure of SAS with the pig as the experimental unit (SAS Institute Inc., Cary, NC, USA). Homogeneity of the variances was confirmed using the UNIVARIATE procedure in SAS. Outliers were identified and removed as values deviated from the treatment mean by more than 3 times the interquartile range. Treatment means were calculated using the least squares means statement in SAS. Orthogonal contrasts for a 2 × 5 factorial arrangement of treatments were used to determine linear and quadratic effects of phytase, the main effect of bakery meal, and bakery meal × phytase interactions. Contrast statements were used with coefficients for unequally spaced treatments being generated using the interactive matrix language procedure in SAS. Block and replicate within block were considered random effects. Statistical significance was considered at $P < 0.05$.

2.3.2. Experiment 2: growth performance

Data were summarized to calculate average daily feed intake (ADFI), average daily gain (ADG), and gain to feed ratio (G:F) within each pen and treatment group. Data were summarized from day 1–14, day 15–35, and for the entire experiment. Data were analyzed using the Mixed Procedure of SAS with the pen as the experimental unit. Homogeneity of variances was confirmed and data were tested for outliers as explained for experiment 1. The model included bakery meal inclusion rate as the fixed effect, whereas block was the random effect. Least squares means were calculated, and linear and quadratic effects of increasing levels of bakery meal on growth performance and diarrhea scores were determined as explained for experiment 1. The frequency procedure of SAS was used to analyze frequency of diarrhea with diet as the fixed effect. Statistical significance and tendencies were considered at $P < 0.05$ and $0.05 \leq P < 0.10$, respectively.

3. Results

3.1. Phosphorus digestibility

The concentration of P in bakery meal 1 and bakery meal 2 was 1.6 and 2.7 g/kg, respectively. Due to increased concentration of P in diets containing bakery meal 2, P intake of pigs fed diets containing bakery meal 2 was greater ($P < 0.01$) compared with that of pigs fed the bakery meal 1 diets (Table 6). Greater reduction in P in feces and fecal P output was observed in pigs fed diets with bakery meal 2 compared with that of pigs fed the bakery meal 1 diets upon phytase supplementation (linear and quadratic interaction, $P < 0.01$). Phosphorus absorption of pigs fed diets with bakery meal 2 increased more than that of pigs fed the bakery meal 1 diets as the concentration of phytase increased (quadratic interaction, $P < 0.05$). As a result, greater increases in coefficients of ATTD and STTD of P in bakery meal 2 was observed as phytase supplementation increased (quadratic interaction, $P < 0.01$). However, due to increased concentration of phytate in bakery meal 2, coefficients for ATTD and STTD of P in bakery meal 1 were greater compared with that of bakery meal 2 ($P < 0.01$).

3.2. Growth performance

There was no effect of increasing concentrations of bakery meal on final body weight, ADG, ADFI, or G:F of pigs from day 1–14 (Table 7). However, ADG of pigs from day 15–35 and for the overall experimental period tended to decrease ($P < 0.10$) as the concentration of bakery meal increased in the diets. The G:F from day 15–35 and for the overall experimental period linearly decreased ($P < 0.01$) as bakery meal inclusion increased in the diets. However, no differences among dietary treatments were observed from day 15–35 or for the overall experimental period for ADFI and the final body weight on day 35 was not different among treatments.

Increasing concentrations of bakery meal in diets did not affect fecal scores or diarrhea frequency of pigs (Table 8). Likewise,

Table 7
Growth performance of pigs fed diets containing increasing levels of bakery meal, experiment 2.[a]

	Corn replacement rate, g/kg						*P*-value	
Item	0	250	500	750	1000	SEM	Linear	Quadratic
Day 1–14								
Initial body weight, kg	7.16	7.18	7.11	7.21	7.13	0.331	0.529	0.815
ADG[b], kg	0.17	0.17	0.18	0.17	0.19	0.011	0.878	0.619
ADFI[b], kg	0.23	0.24	0.24	0.24	0.24	0.014	0.761	0.739
G:F[b]	0.74	0.71	0.76	0.71	0.79	0.034	0.937	0.336
Final body weight, kg	9.54	9.53	9.62	9.53	9.75	0.357	0.777	0.654
Day 15–35								
ADG, kg	0.61	0.60	0.59	0.58	0.53	0.021	0.055	0.150
ADFI, kg	0.88	0.87	0.96	0.93	1.03	0.050	0.126	0.582
G:F	0.70	0.70	0.63	0.63	0.53	0.026	0.003	0.204
Final body weight, kg	22.29	22.20	22.10	21.69	20.84	0.738	0.149	0.316
Day 1–35								
ADG, kg	0.43	0.43	0.42	0.41	0.39	0.013	0.064	0.090
ADFI, kg	0.62	0.61	0.67	0.65	0.71	0.031	0.129	0.714
G:F	0.70	0.70	0.64	0.64	0.54	0.024	0.002	0.147

[a] Data are least squares means of 8 observations for all treatments.
[b] ADG = average daily gain; ADFI = average daily feed intake; G:F = gain to feed ratio.

bakery meal did not affect the concentration of BUN or plasma concentrations of total protein and albumin (Table 9).

4. Discussion

Bakery meal is a high-energy ingredient containing approximately 16.7 MJ of metabolizable energy per kg dry matter (Luciano et al., 2020) due to its high concentrations of starch and fat and low concentration of fiber (Liu et al., 2018; Pinotti et al., 2019). The concentration of protein in bakery meal is low and the digestibility of Lys is sometimes very low due to excessive heating of the ingredients used in manufacturing bakery meal (Almeida et al., 2011; Casas et al., 2015, 2018). Nevertheless, bakery meal may substitute cereal grains in diets for pigs because the chemical composition is close to that of wheat and barley (Pinotti et al., 2019; Luciano et al., 2020). Indeed, by balancing diets for concentrations of digestible nutrients, it is possible to partially substitute traditional sources of energy and crude protein (CP) in animal diets with bakery meal (Pinotti et al., 2014).

4.1. Phosphorus digestibility

Phosphorus needs to be included in diets for pigs because it is the second most abundant mineral in the body (Viveros et al., 2002). The majority of body P is located in bones and teeth, but P is also important in soft tissue, and is involved in many physiological functions in pigs (Almeida and Stein, 2012). Corn, which is one of the major ingredients in pig diets, contains approximately 2.6 g/kg of P (NRC, 2012), but there may be slightly more P in bakery meal (Casas et al., 2018). Therefore, bakery meals can be considered a corn substitute that will provide not only energy and starch (Liu et al., 2018; Luciano et al., 2020), but also minerals (Liu et al., 2018) to diets.

However, P in animal manure may result in environmental pollution (Gerritse and Zugec, 1977) and it is, therefore, important that P nutrition is managed to avoid excessive P excretion from pigs. In cereal grains and grain co-products, oilseed coproducts, and other plant protein sources, more than 50% of P is often bound to phytic acid (Iyayi et al., 2013) in the form of myoinositol phosphate (Nasi, 1990). It is, therefore, common practice to add phytase to diets for pigs (Dersjant-Li et al., 2018) because phytase may release some of the phytate-bound P in the diet, and thereby reduce the need for feed phosphates in the diet (Dersjant-Li et al., 2018).

The concentration of P in bakery meal is somewhat variable as was also illustrated for the 2 sources used in this experiment. The observation that microbial phytase increased the STTD of P in bakery meal is in agreement with Rojas et al. (2013) who observed an increase in the STTD of P in bakery meal if 500 phytase units (FTU) was used. The values for STTD of P in bakery meal 2 without phytase and in the diet with 500 FTU of phytase were in very good agreement with previous values (Rojas et al., 2013). The reason microbial phytase was less effective in increasing the STTD of P in bakery meal 1 than in bakery meal 2 is that bakery meal 1 had a low concentration of phytate, and therefore, a low concentration of phytate-bound P. As a consequence, the STTD of P in bakery meal 1 without phytase was greater than in bakery meal 2 without phytase. Corn co-products and soybean meal with a low amount of phytate-bound P, and therefore a high STTD of P without phytase, also have a lower response to microbial phytase than co-products with more phytate-bound P (Almeida and Stein, 2012; Rojas and Stein, 2012). The difference between bakery meal 1 and 2 in concentration of phytate and the STTD of P is likely a consequence of the different product mixes that may be used in the production of bakery meal. Ingredients with high concentrations of P and phytate (e.g., bran and canola co-products) are often included in bakery meal (Liu et al., 2018), and differences in inclusion rates of these ingredients may explain the differences between the 2 sources of bakery meal used. However, because the product mixes included in the 2 sources of bakery meal used is unknown, we are unable to conclude that differences in phytate concentration were due to different product mixes.

4.2. Growth performance

All animals remained in good health throughout the experiment. The reason ADG and G:F were reduced from day 15–35 and for the overall experiment as greater quantities of bakery meal were used is unclear. Bakery meal may contain bran and cereal co-products (Liu et al., 2018), and these ingredients may have reduced digestibility of energy and AA as bakery meal increased in the diets with a subsequent reduction in G:F of pigs. The observed reduction in G:F with bakery meal inclusion is in contrast with data indicating that pig growth performance was not affected when weanling pigs were fed diets with bakery meal at 300 g/kg (Tretola et al., 2019a). Because bakery meal contains some cooked or baked materials characterized by a greater nutrient digestibility than conventional ingredients, newly weaned pigs were expected to have increased utilization of nutrients from bakery meal compared with corn. The present data, however, indicate that a complete substitution of corn for bakery meal may not be beneficial for pigs after the initial 2 weeks post-weaning and this observation is in agreement with results of other experiments (Tretola et al., 2019b).

The lack of differences in fecal scores of pigs indicates that replacing corn with bakery meal does not elicit a detrimental change in the microbiota profile in the intestinal tract of pigs, and therefore, does not influence intestinal health of pigs. Blood urea nitrogen is an indicator of AA utilization efficiency (Coma et al., 1995), whereas albumin binds and transports AA in the blood (Quinlan et al., 2005). Therefore, the observation that no differences were observed in concentrations of BUN or albumin indicates that absorption and utilization of dietary protein and AA were not affected by replacing corn with bakery meal.

5. Conclusion

Results of the experiments demonstrated that it is possible to include bakery meal in pig diets, although the nutritional composition may vary among sources of bakery meal. By adding phytase to pig diets containing bakery meal, P digestibility may be improved,

Table 8
Diarrhea score and frequency of diarrhea for pigs fed diets containing increasing levels of bakery meal, experiment 2.[a]

	Corn replacement rate, g/kg						*P*-value	
Item	0	250	500	750	1000	SEM	Linear	Quadratic
Diarrhea score[b]								
Day 1–14	1.27	1.27	1.34	1.20	1.34	0.124	0.798	0.878
Day 15–35	1.66	1.58	1.49	1.61	1.54	0.086	0.582	0.407
Day 1–35	1.50	1.49	1.43	1.44	1.46	0.084	0.636	0.572
Frequency of diarrhea								
Day 1–14								
Pen days[c]	56	56	56	56	56			
Frequency[d]	0.00	3.57	7.14	1.79	3.57	–	0.282	
Day 15–35								
Pen days	80	80	80	80	80			
Frequency	7.50	3.75	8.75	10.00	6.25	–	0.600	
Day 1–35								
Pen days	136	136	136	136	136			
Frequency	4.41	3.68	8.09	6.62	5.15	–	0.520	

[a] Data are least squares means of 8 observations for all treatments.
[b] Diarrhea score = 1, normal feces; 2, moist feces; 3, mild diarrhea; 4, severe diarrhea; 5, watery diarrhea.
[c] Pen days = number of pens × the number of days assessing diarrhea scores.
[d] Frequency = (number of pen days with diarrhea scores ≥ 3/pen days) × 100.

Table 9
Blood characteristics for pigs fed diets containing increasing levels of bakery meal, experiment 2.[a]

	Corn replacement rate, g/kg						*P*-value	
Item	0	250	500	750	1000	SEM	Linear	Quadratic
Day 14								
BUN[b], mg/dL	7.63	7.75	6.38	8.88	9.25	0.849	0.155	0.156
Total protein, g/dL	4.78	4.75	4.51	4.69	4.78	0.161	0.644	0.145
Albumin, g/dL	2.66	2.74	2.68	2.74	2.74	0.086	0.535	0.934
Day 35								
BUN, mg/dL	8.75	9.00	8.00	9.00	10.13	0.672	0.537	0.145
Total protein, g/dL	5.39	5.30	5.29	5.30	5.46	0.199	0.911	0.485
Albumin, g/dL	3.13	3.26	3.19	3.33	3.33	0.122	0.231	0.891

[a] Data are least squares means of 8 observations for all treatments.
[b] BUN = blood urea nitrogen.

which can contribute to a reduction of P in manure. Overall gain to feed ratio of pigs was reduced when corn was replaced by bakery meal in the diets; therefore, a complete substitution of corn for bakery meal may not be beneficial for pigs after the initial 2 weeks post-weaning. However, it appears that bakery meal does not influence nutrient metabolism and fecal scores of pigs.

CRediT authorship contribution statement

AL and HHS conceptualized the experiments. AL conducted the animal part of the experiments and summarized data. AL and CDE analyzed data. CDE, LP, and HHS contributed with data interpretation. AL wrote the first draft of the manuscript. CDE, LP, and HHS edited the final version of the manuscript. HHS supervised the project.

Conflict of interest

The authors have no conflicts of interest.

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