RESEARCHREPORT
ANIMAL SCIENCE

Title: An Integrated Evaluation of the Nutrient Uplift Provided by Xylanase in Finishing Diets – **NPB #13-158**

Investigator: Merlin D. Lindemann

Institution: University of Kentucky

Co-Investigator: Young Dal Jang

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Industry Summary:

The current study evaluated the efficacy of xylanase and phytase supplementation to growing-finishing pigs fed diets containing a high amount of by-products (corn DDGS, corn germ meal and wheat middlings) under either restricted or ad libitum feeding conditions.

In Exp. 1, graded levels of xylanase (8,000, 16,000 and 24,000 BXU/kg) were supplemented to diets containing 15% each of corn DDGS, corn germ meal, and wheat middlings (with all diets containing 250 FTU/kg of phytase supplementation) for a balance trial with pigs weighing 75-80 kg to compare apparent total tract digestibility (**ATTD**) of the diets. A positive effect of xylanase supplementation was demonstrated in hemicellulose digestibility with the highest supplementation (24,000 BXU/kg of xylanase) indicating that degradation of insoluble fiber (i.e., arabinoxylan) by the non-starch polysaccharide degrading enzyme supplementation had occurred. This was then associated with a slight increase of energy retention and an energy uplift at approximately 33 kcal/kg for pigs fed that enzyme level.

In Exp. 2, graded levels of phytase (500, 1,000, and 2,000 FTU/kg) were supplemented to grower-finisher diets containing 13% of corn germ meal and 15% each of corn DDGS and wheat middlings that also contained no xylanase or added xylanase (24,000 BXU/kg) to compare growth performance, carcass characteristics, and ATTD (for pigs weighing 110-120 kg). All pigs had free access to feed from 25 to 125 kg body weight. Phytase supplementation clearly increased growth rate and feed efficiency as well as carcass leanness and lean gain, and also increased P digestibility with improvements in the ATTD of dry matter, fat, and fibrous components as supplementation levels increased resulting in an energy uplift of about 44 kcal/kg. However, there was no effect of xylanase supplementation on growth performance, carcass characteristics, and nutrient digestibility which was different from Exp. 1 suggesting that the efficacy of xylanase in pig diets may be dependent on the content of substrates, duration of feeding, feeding regime, and pig age.

In summary, xylanase supplementation can improve fiber digestibility in corn-based diets containing a large amount of byproducts. Also, phytase supplementation can improve digestibility of P and fiber as well as growth performance and carcass leanness. However, when swine producers use xylanase in pig diet, many factors affecting xylanase efficacy (e.g., amount and type of byproducts, age of pig, number of days of supplementation) should be considered to obtain maximized responses.

This study was supported by the National Pork Checkoff.

Key Findings:

- 1. Xylanase supplementation can improve fiber digestibility in corn-based high fiber diets. However, the xylanase response in growing pigs may vary depending on, supplementation level, feeding regime, feeding duration, and age or body weight of pig.
- 2. Phytase supplementation in P-adequate diets can improve growth rate, feed efficiency and carcass leanness as well as digestibility of dry matter, fat, and fiber components in addition to the expected improvement in ATTD of P.
- 3. No significant interaction between xylanase and phytase supplementation on growth performance, carcass characteristics, and nutrient digestibility were observed. However, there may be a potential interaction between these enzymes in feed efficiency in which xylanase supplementation in the phytase-supplemented diets had a slight improvement in feed efficiency over the response with only phytase supplementation.
- **4. Xylanase supplementation to the high by-products diets could uplift the energy release about 33 kcal/kg under limit-fed condition whereas phytase supplementation to the high by-products diets could uplift the energy release about 44 kcal/kg.**

Keywords: xylanase, phytase, pigs, growth performance, nutrient digestibility, carcass characteristics

Scientific Abstract:

Dietary xylanase supplementation can improve energy digestibility of pigs; however, the effect of xylanase supplementation to a diet already containing phytase has not been clearly delineated. Two experiments were conducted to evaluate the effect of xylanase supplementation in grow-finish diets with or without phytase supplementation on growth performance, apparent total tract digestibility (**ATTD**), and carcass characteristics in growing-finishing pigs.

In Exp.1, a total of 25 barrows (mean initial weight: 76.5 kg) were allotted to 5 treatments to evaluate the effect of xylanase supplementation in a balance trial as follows: **1**) positive control [**PC**]: a corn-SBM based diet with 15% each of corn germ meal, corn DDGS, and wheat middlings, **2**) negative control [**NC**]: metabolizable energy (**ME**) was reduced by 103 kcal/kg from the PC diet by replacement of fat with corn starch, **3**) NX1: NC + xylanase (8,000 BXU/kg diet), **4**) NX2: NC + xylanase (16,000 BXU/kg diet), and **5**) NX3: NC + xylanase (24,000 BXU/kg diet). All diets contained 250 FTU of phytase/kg diet. Pigs were adapted to diets for a minimum of 10 days followed by a 7-d adaptation period to the metabolism crates, and then a 5-d fecal and urine collection was performed for determining ATTD. There were no differences in ATTD of dry matter (**DM**), energy, protein, acid detergent fiber, and P. Energy retention in the PC treatment tended to be greater than NC and NX1 and NX2 treatments but similar with the NX3 treatment ($P = 0.09$). In the comparison of xylanase effects, the ATTD of hemicellulose increased linearly with increasing xylanase levels ($P < 0.05$); there were also numerical improvements in ATTD of neutral detergent fiber (**NDF**) at the 24,000 BXU/kg level. The uplift of energy release was 34.2 and 31.0 kcal/kg on a DE and ME basis, respectively.

In Exp. 2, a total of 45 crossbred pigs (mean initial weight: 26.4 kg) were allotted to 9 treatments (a 1 + 2 × 4 factorial arrangement) to evaluate the effect of both xylanase and phytase supplementation in diets for growing-finishing pigs as follows: **1**) PC: a corn-SBM based diet with 15% each of corn DDGS, and wheat middlings and 13% of corn germ meal, **2**) NC: ME was reduced by 103 kcal/kg from the PC diet by replacement of fat with corn starch in each phase, **3**) NC + phytase (500 FTU/kg diet), **4**) NC + phytase (1,000 FTU/kg diet), **5**) NC + phytase (2,000 FTU/kg diet), **6**) NC + xylanase (16,000 BXU/kg diet), **7**) NC + phytase (500 FTU/kg diet) + xylanase (24,000 BXU/kg diet), **8**) NC + phytase (1,000 FTU/kg diet) + xylanase (24,000 BXU/kg diet), **9**) NC + phytase (2,000 FTU/kg diet) + xylanase (24,000 BXU/kg diet). Body weight and feed consumption were recorded to calculate growth performance, and pigs were ultrasonically scanned at the end of the experimental period to measure carcass characteristics. Fecal collection was performed in the late-finishing period for 3 consecutive days to estimate ATTD. There were no differences with xylanase supplementation and no interactions between xylanase and phytase supplementation on growth performance, carcass characteristics and ATTD of energy or nutrients. However, ADG ($P < 0.01$, quadratic) and G:F ratio ($P < 0.05$, linear) for the total experimental period increased as phytase supplementation levels increased. Carcass characteristics, carcass lean percentage and lean gain increased ($P < 0.05$; linear) as phytase supplementation levels increased. The ATTD of DM, NDF, EE ($P < 0.05$), and hemicellulose increased ($P = 0.05$; quadratic) as phytase supplementation level increased resulting in the uplift of energy release of 44.1 kcal/kg. The ATTD of P increased as phytase supplementation levels increased ($P < 0.05$, linear and quadratic).

These results indicate that xylanase supplementation to the high fiber, corn-based diet improves some aspects of fiber digestibility and phytase supplementation improves growth performance, carcass leanness, and digestibility of fibrous components and P. Furthermore, the efficacy of xylanase supplementation may depend on dose, substrates, and feeding duration.

This project was funded by the National Pork Checkoff.

Introduction:

The U.S. swine industry has been confronted with increased ingredient costs over the last decade, mainly because of increased international demands for corn and oil seeds and/or increased use of these products for biofuels production (most notably, ethanol). Therefore, utilization of by-products as feed ingredients becomes important to reduce feed costs and enhance the sustainable use of feed resources. However, high dietary fiber in swine diets from by-products may result in decreased nutrient and energy utilization (Metzler and Mosenthin, 2008; Stein and Shurson, 2009). Many by-products commonly used in swine diets such as corn DDGS, corn germ meal, and wheat middlings contain high levels of plant cell wall materials (i.e., arabinoxylan) and phytate which cannot be digested by mammalian enzymes (Nortey et al., 2008; NRC 2012; Rojas et al., 2013). Pigs poorly digest arabinoxylan and phytate in feed ingredients because digestive enzymes for degrading them are not secreted by the mammalian gastrointestinal tract. Therefore, supplementation of exogenous enzymes (e.g., xylanase and phytase) may be a useful means to enhance nutrient utilization by degrading the target substrates such as arabinoxylan and phytate.

Xylanase supplementation improves fiber digestibility by degrading arabinoxylan, and phytase supplementation responds consistently to improve P digestibility, in wheat-based diet (Kim et al., 2005; Atakora et al., 2011) and diet containing DDGS (Yáñez et al., 2011). Olukosi et al. (2007) reported that the combination of phytase and xylanase supplementation in diets containing wheat and wheat middlings improved P digestibility of growing pigs. However, other studies have reported that simultaneous inclusions of xylanase and phytase in diets for growing pigs had no synergistic effects in nutrient digestibility, even though individual supplementation of these enzymes had positive effects to improve nutrient digestibility (Atakora et al., 2011; Woyengo et al., 2008). Additionally, some previous studies suffered from: not having high fiber, diets not containing phytase, or methodology that does not mimic industry (i.e., it uses limit-fed pigs in metabolism crates where transit time of digesta is altered). Thus, the inclusion of energy-releasing enzymes (such as xylanase) in conjunction with phytase to diets containing multiple by-products in industry-like conditions is notably lacking. Therefore, additional research needs to be conducted to understand how advantage can be taken of the energy in fiber from byproducts such as corn DDGS, wheat middling, and corn germ meal in corn-based diets (typical of US production compared to wheat-based diets typical of some other countries) with or without phytase as a co-factor under production practices (i.e., feeding levels, ingredient usage).

Objectives:

The objective of this project was to evaluate apparent total tract digestibility (**ATTD**) and energy release from a xylanase enzyme with or without phytase in corn-based diets containing high fiber by-products such as corn DDGS, wheat middling, and corn germ meal in **1**) meal-fed pigs in a metabolism study, as well as in **2**) ad libitum-fed pigs with additional comparison of these enzyme effects on growth performance and carcass characteristics.

Materials and Methods:

The experiment was conducted under protocols approved by the University of Kentucky Institutional Animal Care and Use Committee and followed guidelines stated in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

Animals and housing, treatments and diets

Experiment (Exp) 1.

A total of 40 finishing pigs [8 sets of 5 genetically-matched barrows; body weight (**BW**) range 60-80 kg] were randomly assigned within set to 5 experimental diets and housed 1 or 2 pigs per pen at the research farm. Each assigned experimental diet was provided to pigs ad libitum for 10-12 days for diet adaptation. After adapting to the diets, a subset of pigs (n=25; the 5 most uniform sets of 5 barrows; mean initial BW = 76.5 ± 0.6 kg) were selected for total collection of feces and urine, and individually housed in stainless steel metabolism crates in a mechanically ventilated room at room temperature. After a 7-d adaptation period to the crate, feces and urine were collected for 5 consecutive days by the marker-to-marker method. The experiment was split into 3 separate collection groups (Group 1, 10 pigs; Group 2, 10 pigs; Group 3, 5 pigs). The same process of adaptation and collection for Group 1 was repeated with Groups 2 and 3. As stated, a total of 5 experimental diets were used with increasing xylanase (Econase XT; AB vista Feed Ingredients, Marlborough, UK) supplementation levels. All diets were supplemented to contain 250 FTU of phytase/kg diet (Quantum Blue; AB Vista Feed Ingredients, Marlborough, UK).

The dietary treatments were as follows:

1) Positive control (**PC**)
2) Negative control (**NC**) in which metabolizable energy (**ME**) is reduced from the PC diet by 103 kcal/kg diet (the reduction was accomplished by changing the replacing a portion of the fat in the PC diet with corn starch),
3) NX1: NC + 8,000 BXU of xylanase/kg diet,
4) NX2: NC + 16,000 BXU of xylanase/kg diet, and
5) NX3: NC + 24,000 BXU of xylanase/kg diet

A corn-SBM basal diet with 15% each of DDGS, corn germ meal, and wheat middlings was used for the experiment. The basal diet met or exceeded all NRC (2012) nutrient requirement estimates. Diet formulation and chemical composition are shown in Table 1, and analyzed enzyme activity (xylanase and phytase) is shown in Table 2.

Pigs were fed at 2.7% of BW during the experiment in a gruel form (feed:water, 1:1 wt/vol), with the feed divided into 2 meals/d. The beginning and end of the total collection period were marked by the addition of 0.5% indigo carmine to the morning meal (as described by Adeola, 2001). After consumption of each meal, water was provided ad libitum between meals. Feces were collected twice daily when each meal was provided. Urine collection commenced on day 1 at 1330 and ceased on day 5 at 1330. Urine was collected in plastic buckets containing 150 mL of 3N hydrochloric acid to prevent ammonia evaporation. Orts were recorded at each meal to determine daily feed consumption.

The total amounts of feces were collected, stored in plastic bags, and frozen at -20°C until the end of the collection period. At the end of the collection period, the collected feces were thawed, dried in a forced-air drying oven at 55°C for 1 week, then air-equilibrated, weighed, and ground through a 1 mm screen using a Wiley Laboratory Mill (Model 3, Arthur H. Thomas Co., PA) for chemical analyses. All ground feces were mixed in a single bag for each pig, and then stored at 4°C until analysis. When urine was collected, a 100-mL aliquot was taken, and frozen at -20°C until the end of the collection periods. At the end of the collection period, urine samples were thawed, mixed on a per-animal basis, and sub-sampled proportionally for further storage until analysis.

Experiment 2.

A total of 45 grower pigs (27 barrows and 18 gilts; mean initial BW = 26.4 ± 0.3 kg) were used for a growth performance and ATTD trial. The pigs were blocked by BW and sex and randomly assigned to 9 dietary treatments in a randomized complete block design. Each treatment had 5 replicates including 3 replicates of barrows and 2 replicates of gilts. The pigs were housed in individual pens equipped with water nipples, stainless steel feeders, and slatted concrete floors located in an environmentally controlled research facility. Feed and water were provided ad libitum.

The dietary treatments were:

1) Positive control (**PC**)
2) Negative control (**NC**) in which the ME is reduced from the PC diet by 103 kcal/kg diet in each phase (the reduction was accomplished by changing the level of fat in the diet and replacing with corn starch)
3) NP500: NC + phytase at 500 FTU/kg
4) NP1000: NC + phytase at 1,000 FTU/kg
5) NP2000: NC + phytase at 2,000 FTU/kg
6) NX: NC + optimal dose of xylanase from Objective 1
7) NXP500: NC + phytase at 500 FTU/kg + optimal dose of xylanase from Exp 1
8) NXP1000: NC + phytase at 1,000 FTU/kg + optimal dose of xylanase from Exp 1, and
9) NXP2000: NC + phytase at 2,000 FTU/kg + optimal dose of xylanase from Exp 1

The optimal dose of xylanase from Exp 1 was 24,000 BXU/kg of diet based on its providing the greatest hemicellulose and NDF digestibility. The same products of xylanase and phytase used in Exp 1 were supplemented in the diets for Exp 2.

A corn-SBM based diet with 15% each of DDGS, wheat middlings and 13% of corn germ meal was used for the experiment. The basal diet met or exceeded all NRC (2012) nutrient requirement estimates. Diets were formulated in 4 dietary phases by BW range (Phase 1, 25-50 kg; Phase 2, 50-75 kg; Phase 3, 75-100 kg; Phase 4, 100-125kg, respectively) and 0.30% TiO_2 was included in Phase 4 diets as an indigestible marker for ATTD determinations. Because the objective of the experiments targeted potential energy release, diets in all phases were formulated to provide adequate P apart from that released by phytase. Diet formulation and chemical composition are shown in Table 3, and analyzed enzyme activity (xylanase and phytase) is shown in Table 4.

Body weight and feed consumption were recorded for calculation of ADG, ADFI and G:F ratio. Fecal collections were performed during Phase 4 after pigs had received the treatment diets for at least 10 days. Fecal samples were collected for 3 consecutive days, stored in plastic cups, and frozen at -20°C for each collection day. The collected feces were dried in a forced-air drying oven at 55°C for 1 week, and ground through a 1 mm screen using a Wiley Laboratory Mill (Model 3, Arthur H. Thomas Co., PA) for chemical analyses. All ground feces were mixed in a single bag for each pig, and then stored at 4°C until analysis.

When pigs reached a BW of about 120 kg, pigs were scanned by real-time ultrasound (User's Manual for AUSKey System; AUSKey System v. 2.0, Animal Ultrasound Services, Ithaca, NY) by an experienced technician, and backfat thickness and longissimus muscle (**LM**) depth were measured.

Diet mixing procedures

For each experiment, large quantities of the basal diet were mixed, to which fat (PC diet) or enzymes (xylanase and/or phytase) were then incorporated; this prevented differences in non-treatment components of the diets. In Exp. 1, a single batch of the basal diet was prepared and then divided into 5 fractions. One fraction was mixed with additional fat for the PC diet. The rest of the fractions collectively had corn starch added (the same amount as fat in the PC diet), and then divided into 2 fractions. One of the fractions was blended with xylanase at the greatest concentration (24,000 BXU/kg; NX3) and another one remained without xylanase (the NC diet). To make experimental diets NX1 (8,000 BXU/kg) and NX2 (16,000 BXU/kg), a part of NC and NX3 diets was proportionally blended. In Exp. 2, a single batch of the basal diet was prepared and then divided into 9 fractions. One fraction was mixed with additional fat for the PC diet. The rest of fractions collectively had corn starch added (the same amount as fat in the PC diet), and then were divided into 3 fractions. One of the fractions remained unblended (NC diet), another one was blended with xylanase and the third one was blended with phytase, with the blending of both enzymes (xylanase and phytase) done in a proportion equivalent to twice the desired concentration (i.e., 48,000 BXU/kg of xylanase and 4,000 FTU/kg of phytase). To make the rest of experimental diets, a part of each concentrated portion was blended proportionally with the NC diet.

Laboratory analysis

All feed and fecal samples were analyzed for dry matter (**DM**), gross energy (**GE**), ether extract (**EE**), crude protein (**N**), neutral detergent fiber (**NDF**), acid detergent fiber (**ADF**), Ca, and P. Urine samples (in Exp 1) were analyzed for GE, N, Ca, and P to calculate energy and nutrient retention. Hemicellulose content was determined by subtracting ADF from NDF content. Samples were analyzed in duplicate, and analysis was repeated when abnormal variation was observed (when the CV was > 5% for the duplicate assays).

Dry matter in feed and feces was assessed according to the AOAC (1995a) method, involving overnight drying (105°C) of the samples in a convection oven (Precision Scientific Co., Chicago, IL). Gross energy contents were assessed by bomb calorimetry (Model 1261 Isoperibol Bomb Calorimeter; Parr Instruments Co., Moline, IL). Ether extract was analyzed using Soxhlet extraction (920.39; AOAC 2006). Nitrogen was measured using Dumas methodology in an automatic N analyzer (Model FP-2000; LECO Corp., Saint Joseph, MI). Calcium was assessed by flame atomic absorption spectrophotometry (AAS; Thermoelemental, SOLAAR

M5; Thermo Electron Corp., Verona, WI) according to a modification of the AOAC procedure (Method 927.02; AOAC, 1995b). Phosphorus was assessed by a gravimetric method (modification of method 968.08; AOAC, 1990). Acid detergent fiber was analyzed by the AOAC procedure (Method 920.39; AOAC, 2006) and NDF was analyzed as described by Van Soest et al. (1991). Titanium concentration in feed and feces in Exp 2 was assessed as described by Myers et al. (2004). Titanium, ADF, and NDF were analyzed at the University of Missouri Experiment Station laboratories.

Calculation of Apparent Total Tract Digestibility and Retention of Energy and Nutrients

The ATTD in Exp. 1 was determined using the total collection method. For ATTD calculation in Exp. 1, averaged values of nutrients from all diets were used except GE and fat in which averaged values of nutrients from NC, NX1, NX2 and NX3 were used for all of the lower energy diets separately from the PC diet. The ATTD in Exp. 2 was calculated by the indirect method using TiO_2 as an indicator. For ATTD calculation in Exp. 2, averaged values of nutrients from all diets were used except GE and fat in which averaged values of nutrients from NC, phytase and xylanase supplemented diets were used for all of the lower energy diets separately from the PC diet. The formula to calculate ATTD was:

$$\text{ATTD}\ (\%) = [1 - (T_{diet}/T_{digesta}) \times (N_{digesta}/N_{diet})] \times 100$$

where T_{diet} = Ti concentration in the diet; $T_{digesta}$ = Ti concentration in the feces; $N_{digesta}$ = nutrient concentration in the feces; and N_{diet} = nutrient concentration in the diet.

Gross energy or nutrient (N, Ca, and P) retention (g/d) in Exp 1 was calculated by subtracting fecal and urinary excretion (g/d) of GE or nutrients from total intake (g/d) of GE and nutrients. Then, GE or nutrient retention was expressed relative to the total intake as well as to the amount absorbed. Digestible energy (DE) and ME was calculated using following equations:

DE = [GE intake (kcal/d) – Fecal GE excretion (kcal/d)] / feed allowance (kg/d).

ME = [GE intake (kcal/d) – Fecal GE excretion (kcal/d) – Urinary GE excretion (kcal/d)] / feed allowance (kg/d).

Carcass characteristics

Longissimus muscle area was estimated from the LM depth for each pig. The percent of carcass lean was estimated from backfat thickness and LM depth. Equations were as provided by the User’s Manual for AUSKey System adapted to metric units. Equations were as follows:

LM area, $\text{cm}^2 = 4.174 + (5.987 \times \text{LM depth, cm})$

Percent of carcass lean, $\% = 58.457 - (6.00 \times \text{backfat thickness, cm}) + (1.181 \times \text{LM depth, cm})$

Carcass daily lean gain was estimated by subtracting the kilograms of initial lean for each pig from the kilograms of final lean, and then dividing by the number of days on test. The weights of initial and final lean were calculated from the NPPC (2000) equation as follows:

Initial lean, kg = [(0.418 × initial wt., lb) – 3.650] / 2.2

Final lean, kg = [0.833 × sex (barrow=1, gilt=2) – 16.498 × (10th rib backfat, in) + 5.425 × (10th rib LM area, in^2) + (0.291 × live wt., lb.) – 0.534] / 2.2

Following calculation of the daily lean gain during the overall period, the ADFI during the overall period was compared to the lean gain to create a lean gain to feed efficiency ratio.

Statistical analysis

In Exp. 1, one pig was excluded from the data set due to a sudden leg injury in the adaptation period. Data on ATTD and retention were subjected to ANOVA using the GLM procedure in SAS (Statistical Analysis System, Cary, NC) with a randomized complete block design. The individual pig served as the experimental unit. The model included the effects of treatment and replication. Orthogonal polynomial contrasts were performed to evaluate linear and quadratic effects of xylanase supplementation levels. Least squares mean separations were accomplished using the PDIFF option of SAS. Statistical differences were considered as significant at $P < 0.05$ and as a tendency at $P < 0.10$.

In Exp. 2, data on growth performance, carcass characteristics, and ATTD were subjected to ANOVA using the GLM procedure in SAS (Statistical Analysis System, Cary, NC) with a randomized complete block design. The individual pig served as the experimental unit. In the comparison of dietary treatment effects, the model included the effects of treatment and replication. A single degree of freedom contrast was performed for the comparison between PC and NC treatments to validate the experimental design. Apart from the PC treatment, the treatment structure was a 2 × 4 factorial arrangement with the main factors of xylanase and phytase supplementation, and the model included the effects of replication, xylanase, phytase, and xylanase × phytase interaction. Orthogonal polynomial contrasts were performed to evaluate linear and quadratic effects of phytase supplementation levels. Least squares mean separations were accomplished using the PDIFF option of SAS. Statistical differences were considered significant at $P < 0.05$ and tendency at $P < 0.10$. For the analysis of carcass characteristics, the BW at real-time ultrasound scan was considered as a covariate. The final BW and feed consumption were analyzed on both a common weight and a common age basis to assess potential differences in treatment effects between data using the same feeding duration (common age) and using a common end weight (different days on test but analogous to feeding to a common market weight).

Because there were no significant interactions between phytase and xylanase supplementation for any response measures, additional analyses were performed to assess the individual treatment effect of phytase (NP500, NP1000, and NP2000) or xylanase (NX) supplementation compared to the control diets (PC and NC) by ANOVA using GLM procedure in SAS. These data and statistics are presented in Appendix tables 1-6 but not discussed.

Results:

Experiment 1.

There were no differences in the ATTD of DM, GE, N, ADF, or P (Table 5). However, the PC treatment had the greatest ATTD of EE ($P < 0.05$) and the lowest ATTD of Ca ($P < 0.05$) among all dietary treatments. Energy retention as a % of total intake in the PC treatment tended to be greater than the NC, NX1 and NX2 treatments while it was similar with the NX3 treatment ($P = 0.09$). Digestible energy and ME values were the greatest in the PC treatment among all dietary treatments ($P < 0.05$) as they should have been based on the formulation with added fat. Calcium retention as a % of total intake and as a % of energy absorbed were the lowest in the PC treatment among dietary treatments ($P < 0.05$) while P retention as a % of P absorbed was greater in the PC treatment than the NX1, NX2, and NX3 treatments ($P < 0.05$).

In the comparison of the xylanase effects, the ATTD of hemicellulose increased linearly ($P < 0.05$) and quadratically ($P = 0.101$) with increasing xylanase supplementation levels and was associated with a linear tendency ($P = 0.07$) for a decrease in fecal hemicellulose excretion.

Based on the DE and ME values of the diets, energy uplifts by xylanase supplementation were calculated. Xylanase supplementation at 24,000 BXU/kg increased the DE and ME values of the high by-products diets by 34.2 and 31.0 kcal/kg, respectively from the NC diet for the limit-fed pigs.

Experiment 2.

Daily P intake for pigs in Exp. 2 is presented in Table 6. There were no differences in daily P intake among all dietary treatments. However, daily P intake for all treatments was above daily P requirement estimates (NRC, 2012).

Comparing the PC to NC treatments for growth performance (Table 7), the PC treatment had greater BW at the end of Phase 3 ($P = 0.07$) and 4 ($P = 0.10$ and 0.04 for common weight and common age basis, respectively). The PC treatment also had greater ADG for Phase 3 ($P < 0.05$), 4 ($P = 0.08$; common age basis), and the overall period ($P < 0.05$), and greater G:F ratio than the NC treatment for all periods ($P < 0.05$; $P < 0.06$ for Phase 4) except Phase 1.

When evaluating all 9 treatments together, there were no treatment effects for BW, ADG, ADFI and G:F ratio except that pigs fed the PC diet had the greatest G:F ratio at Phase 3 ($P < 0.05$) and for the overall period (a tendency on the common weight basis; $P = 0.088$); however, the G:F ratio for the phytase only supplementation at 2,000 FTU/kg level (NP2000) and the combined xylanase and phytase supplementation (NXP500, NXP1000, and NXP2000) were not different from that in the PC treatment.

For the main effects of xylanase and phytase supplementation (Table 8), there were no significant differences with xylanase supplementation (all $P > 0.10$) and no interactions between xylanase and phytase supplementation (all $P > 0.22$). However, there were quadratic increases with increasing phytase supplementation levels in BW at Phase 1, 2, 3, and 4 ($P < 0.05$), ADG at Phase 1 ($P = 0.06$), 2, 4, and overall ($P < 0.05$), tendencies for increase in ADFI at Phase 3 ($P = 0.07$) and 4 ($P = 0.09$), and linear increases in G:F ratio for Phase 2 ($P = 0.095$) and overall ($P < 0.05$ and $P = 0.06$ for the common weight and age basis, respectively).

Regarding carcass characteristics on a common ending weight basis and using scan weight as a covariate (Tables 9), there were no overall differences by treatment (all $P > 0.22$) and no interactions between xylanase and phytase supplementation (all $P > 0.34$). However, the PC treatment tended to have greater lean gain to feed ratio compared to the NC treatment on both a common weight and common age basis ($P = 0.06$). In evaluating the main effects of the enzymes (Table 10), on a common age basis carcass lean percentage ($P < 0.05$), final lean weight ($P < 0.05$), daily lean gain ($P < 0.05$; also observed on a common weight basis), and lean gain to feed ratio increased ($P < 0.05$; also observed as a tendency for the common weight basis, $P = 0.06$) linearly as phytase supplementation increased. Backfat thickness, on a common age basis, tended to decrease linearly as phytase supplementation levels increased ($P = 0.098$).

Regarding the Phase 4 ATTD results (Table 11), the ATTD of DM, NDF, and hemicellulose were the lowest in the PC treatment among all dietary treatments with statistically comparable values for the no phytase treatments (NC and NX; $P < 0.05$). The ATTD of EE was greater in the PC treatment compared with no phytase treatments (NC and NX) but statistically similar with all phytase-including treatments ($P < 0.05$). The ATTD of P was also the lowest in the PC treatment among all dietary treatments while the other treatments as well as the NC treatment had greater ATTD of P compared with the PC treatment ($P < 0.05$). For the enzyme supplementation main effects (Table 12), the ATTD of DM, EE, NDF, and hemicellulose increased quadratically as phytase supplementation increased ($P \leq 0.05$). The ATTD of P increased both linearly ($P < 0.01$) and quadratically ($P < 0.05$) as phytase supplementation levels increased. The ATTD of GE for the phytase treatments tended to be greater than that in the NC treatment ($P = 0.09$). However, there was no difference in the ATTD of DM, GE or any nutrient with xylanase supplementation and no interactions between xylanase and phytase supplementation (all $P > 0.14$).

Based on the ATTD of GE results, nutrient uplifts by phytase supplementation were calculated. The averaged ATTD of GE of phytase supplementation treatments (500, 1,000, and 2,000 FTU/kg) was 78.2% which represents an absolute increase of 1.1% from the no phytase treatment. Thus, the energy uplift by phytase supplementation was 44 kcal/kg by multiplying the GE value of the Phase 4 diets by the absolute increase of its ATTD.

Discussion:

In both Exp 1 and 2, a variety of differing high fiber and phytate-including ingredients such as corn germ meal, corn DDGS, and wheat middlings were used to provide enough substrate for possible xylanase and phytase responses. As a result of inclusion of these ingredients in the diets at 45% (Exp. 1) and 43% (Exp. 2), the experimental diets contained greater amount of fiber and phytate compared to that normally present in traditional corn-SBM based swine diets (Selle and Ravindran, 2008; Rojas et al., 2013).

The daily P allowance in Exp. 1 (Table 5) and daily P intake in Exp. 2 (Table 6) were greater than the daily P requirement estimates of NRC (2012). For Exp. 1, phytase was supplemented in all diets, and graded levels of phytase were supplemented to the diets in Exp. 2. Therefore, results for both studies are responses beyond the P-releasing action of the phytase.

Experiment 1.

This study evaluated the effect of xylanase supplementation at graded levels for growing pigs fed high fiber diets compared to a high energy diet to demonstrate whether xylanase can improve energy release by degrading xylan in the diets. The analyzed xylanase activities were confirmed and the graded xylanase supplementation levels were as expected.

In this study, fat digestibility was greater in the high energy diet compared to the low energy diet which agrees with previous studies that reported increased fat digestibility with fat supplementation (O'Doherty et al., 2002; Dégen et al., 2009; Kil et al., 2010). Kil et al. (2010) reported greater digestibility and smaller endogenous fat losses in extracted lipids than intact lipids in the ingredients. Because in the present study, energy difference was induced by addition of extracted fat (choice white grease), greater total diet fat digestibility was most likely due to the increased digestibility of the fat added to the PC diet. However, total diet energy digestibility was not affected by the dietary fat content. This result agrees with previous studies reporting that inclusion of fat in the diets did not increase energy digestibility even though fat digestibility increased with the additional fat (O'Doherty et al., 2002; Dégen et al., 2009). DeRouchey et al. (2004) also reported in a nursery pig study that 6% addition of choice white grease increased fat digestibility but not energy digestibility. In terms of properties of fat sources, Powles et al. (1993) reported that DE values of lipids decreased with increasing free fatty acid content in the diet. Free fatty acids produced during digestion in the intestinal tract can form insoluble soaps by binding with Ca or other minerals (Atteh and Leeson, 1983) which has potential to limit availability of both the fat and Ca. Therefore, it is possible that energy derived from lipids was limited by insoluble soap formation between fat and Ca resulting in no effect of fat inclusion on energy digestibility. Additionally, Kil et al. (2010) reported that inclusion of fat in grower diet increased ATTD of fat but did not increase true total tract digestibility of fat, and that endogenous loss of fat affected ATTD but not true total tract digestibility.

Even though an improvement in energy digestibility was not observed in this study, energy retention, DE, and ME values were increased by additional fat inclusion to the diet. This result can be attributed to greater energy intake in the PC treatment than the other treatments combined with a similar energy digestibility among dietary treatments. O'Doherty et al. (2002) reported that even though energy digestibility may be reduced slightly, DE values increase with fat supplementation.

Calcium digestibility and retention was the lowest in the PC treatment among dietary treatments. As mentioned above, both fat and Ca utilization could be limited by the insoluble Ca soap formation in the gut lumen in the digestion process (Atteh and Leeson, 1983). Tancharoenrat and Ravindran (2014) reported that increasing dietary fat increased soap concentration in the ileal digesta and decreased Ca digestibility in broilers.

Phosphorus digestibility was not affected by treatments. However, P retention as a % of absorption was the greatest in the PC treatment among all dietary treatments (which, of course, resulted from lower urinary P excretion in the PC treatment). Increased DE intake is linearly correlated with body protein deposition (King et al., 2004) and there is a positive correlation between protein (N) and P deposition in the body (NRC 2012; Pettey et al., 2015) which means that higher energy intake may increase metabolic demand for P in the body when it is associated with increased protein deposition in muscle tissues which, consequently, may result in the reduction of urinary P excretion. However, as stated, P digestibility did not differ with xylanase supplementation in these diets already containing a low level of phytase supplementation diets.

Xylanase supplementation improved hemicellulose digestibility. This result agrees with Jang et al. (2013) who reported that xylanase supplementation slightly increased ATTD of ADF, NDF, and hemicellulose. Hemicellulose is insoluble cell wall non-starch polysaccharides (**NSP**) in cereal grains and mainly contains arabinoxylans. Arabinoxylans have negative effects in nutrient digestibility of pigs by increasing fecal bulk and decreasing intestinal transit time (Montagne et al., 2003). Corn DDGS, corn germ meal, and wheat middlings are feed ingredients that contain high dietary fiber (NRC, 2012). Jaworski et al. (2015) analyzed the content of xylose in these ingredients, and reported that most of the xylose content belongs to insoluble NSP (82 to 98% of total xylose content). Because xylanase can hydrolyze arabinoxylans to liberate xylose and arabinose (Berrin and Juge, 2008), it is clear that xylanase supplementation can influence hemicellulose digestibility. Zhang et al. (2013) reported that an increase of insoluble dietary fiber digestibility could result in an improvement of total dietary fiber digestibility and its effect was larger than that of soluble dietary fiber digestibility. In this study xylanase supplementation increased hemicellulose digestibility which was evident in the numerical, though statistically nonsignificant, increase in NDF digestibility.

Additionally, while xylanase supplementation had no effect on energy digestibility, it improved energy retention slightly at the supplementation level of 24,000 BXU/kg similar to that in the high energy PC diet and uplifted the energy release at approximately 33 kcal/kg of either DE or ME. This result may indicate that the positive effect of xylanase supplementation on hemicellulose digestibility may be able to improve energy utilization.

Experiment 2.

Based on the results of Exp. 1, Exp. 2 evaluated the combined effects of xylanase and phytase supplementation for growing-finishing pigs fed high fiber diets in a factorial arrangement of treatments compared to higher energy diet to evaluate effects on nutrient utilization and energy release as well as growth performance and carcass characteristics. The graded phytase activity and xylanase activity were confirmed in the supplemented diets.

With regard to growth performance, the higher energy PC diet had greater feed efficiency than the lower energy NC diet as would be expected. However, the overall G:F ratio increased slightly when the high level of phytase was supplemented to the diet with no xylanase supplementation or when xylanase was supplemented to the diet combined with phytase supplementation; these diets resulted in no statistically significant difference from the PC diet. This result indicates that certain levels of phytase supplementation alone or combinations of xylanase and phytase supplementation can improve feed efficiency of growing-finishing pigs.

In this study, phytase supplementation clearly improved weight gain and feed efficiency and 1,000 FTU of phytase supplementation had the greatest growth rate during the entire experimental periods. Phytase can degrade phytate in cereal grains and plant sources and liberate nutrients that are bound to phytate as well as P, and therefore, more nutrients could be available for pigs fed the phytase-containing diets (Selle and Ravindran, 2008). Zeng et al. (2014) reported that weight gain and feed efficiency of weaning pigs increased as phytase supplementation levels increased in a low-P diet. Braña et al. (2006) also reported that there were linear increases in ADG and G:F ratio as phytase supplementation levels increased in low-P diets for growing-finishing pigs. Those previous studies demonstrated that phytase supplementation in low-P or P-deficient diets for growing-finishing pigs improved growth rate and feed efficiency with increased P digestibility. However, because of the formulated level of P in the experimental diets herein and a greater feed intake in this study than NRC (2012) estimates, all pigs in this study consumed P above their daily requirement estimates (NRC, 2012). It has been reported that the efficacy of phytase supplementation on P digestibility could be diminished when phytase was supplemented to diets containing P above the requirement (Kemme et al., 1997; Jang et al., 2014). While this is obvious and logical, P digestibility did still increase as phytase supplementation levels increased and this study still observed quadratic increases in digestibility of DM, NDF and hemicellulose as phytase supplementation levels increased with slight increases in energy digestibility also observed. Therefore, the improvements in growth rate and feed efficiency can be attributed to phytase supplementation effects beyond P release which may include increased digestibility of fibrous components.

In this experiment, there was no effect of xylanase supplementation on carcass characteristics which is consistent with the growth performance and ATTD results. However, carcass leanness was improved with phytase supplementation as shown by increased LM depth, LM area, carcass lean percentage, lean gain, and lean gain to feed ratio as phytase supplementation levels increased. It has been demonstrated that an increased P deposition is associated with an increased N deposition of pigs (NRC, 2012; Pettey et al., 2015). Therefore, phytase supplementation increased P availability which could increase carcass leanness of pigs provided other nutrients are available and that genotypic lean deposition has not been reached. It should be noted that Shelton et al. (2003) reported no effect of phytase supplementation on LM area and backfat thickness as well as growth performance when supplemented with 500 FTU/kg of phytase. Therefore, observed phytase effects on growth and carcass characteristics of pigs may depend on a variety of factors, some of which may be absent in some previous studies on phytase, including type of dietary ingredients, other nutrient levels, and supplementation level.

In the evaluation of effects in ATTD, fat digestibility was greater in the PC diet compared with the lower energy diets with no phytase supplementation (NC and NX) which was demonstrated again in Exp. 2. The diets with no phytase supplementation (PC, NC and NX) had lower digestibility of DM, NDF, and hemicellulose as well as P compared with the phytase-supplemented diets, strongly demonstrating that phytase supplementation increased digestibility of fat, P, and fiber components. While digestibility of DM, NDF, and hemicellulose were not statistically different among non-phytase treatments, the PC treatment had statistically lower P digestibility compared with the NC treatment. The sole difference between the PC and NC treatments was energy level in the diet derived from different dietary fat content and therefore, phytate content, a substrate of phytase, in the diets between PC and NC was equal. Therefore, it can be suggested that P digestibility can be affected by the level of supplemental dietary fat. One possibility of this effect might be an interaction between phytate, lipids and minerals such as Ca and Mg to form soaps resulting in reductions of their availability. However, because of no difference in Ca digestibility, further study is needed to investigate the effect of dietary fat levels on P digestibility.

In this study, phytase supplementation increased digestibility of DM, energy, EE, P, and fibrous components (NDF and hemicellulose) resulting in an uplift of energy release at 44 kcal/kg. It is well-known that phytase supplementation increases P digestibility in pigs (Kerr et al., 2010). In this study, P digestibility had a quadratic increase where ATTD of P was maximized when phytase was supplemented over 1,000 FTU/kg which agrees with Almeida et al. (2013) who reported that ATTD of P in growing pigs plateaued when phytase was added to the diet at 801 FTU/kg based on the broken line analysis with graded phytase supplementation levels in low-P diets. Regarding fat digestibility, it has been reported that phytate could decrease fat digestibility by reducing porcine pancreatic lipase activity and by binding bile acids with Ca to form insoluble phytate-mineral-bile acid complexes in pigs and broilers (Woyengo and Nyachoti, 2013). Therefore, degrading phytate with phytase supplementation could enhance fat digestibility by alleviating these particular negative effects of phytate on fat digestion and absorption. In this study, the increase of DM and energy digestibility can also be attributed to the increases of NDF and hemicellulose digestibility which agrees with Bento et al. (2012) who reported that DM digestibility increased as phytase supplementation levels increased up to 2,000 FTU/kg in weaned pigs. Woyengo et al. (2008) reported that phytase supplementation at 500 or 1,000 FTU/kg levels improved DM digestibility in growing pigs fed wheat-based diets. Nortey et al. (2007) reported that phytase supplementation improved ileal DM and energy digestibility of growing pigs fed the diets containing 20 and 40% of wheat millrun with a slight increase in total tract DM digestibility. However, the effects of phytase supplementation on fibrous components are still inconsistent, and rather limited information about the effects of high level of phytase supplementation on fiber digestibility of pigs fed high fiber diets is available. Johnston et al. (2004) reported that ileal NDF digestibility increased when 500 FTU/kg of phytase was supplemented in the diet with adequate level of Ca and P but there was no phytase effect in the Ca/P-deficient diets. The microbial fibrolytic activity in the large intestine largely depends on the P availability in pigs because P is essential for fiber degradation by microbes, and P availability for microbes in the large intestine could potentially be reduced by increased small intestine P absorption mediated by the phytase response in the small intestine (Metzler and Mosenthin, 2008). Bruce and Sundstøl (1995) reported no effect of phytase supplementation on ileal crude fiber digestibility. Lindeberg et al. (2007) reported that 500 FTU/kg of phytase supplementation had no effect on ATTD of NDF and CP. Again, the effects of phytase supplementation on fibrous components are inconsistent, though frequently observed, and worthy of further research.

Based on the improvements in digestibility of hemicellulose in Exp 1, the hypothesis in Exp. 2 was that there may be a greater improvement in digestibility of fibrous components as a result of a longer period of feeding the xylanase-supplemented diets in Exp 2. Unlike Exp 1, however, the effect of xylanase supplementation in the ATTD was not observed in Exp 2. Xylanase supplementation effects on nutrient digestibility are still inconsistent. Even though the positive effect of xylanase supplementation on nutrient digestibility was reported in previous studies (O'Connell et al. 2006; Nortey et al., 2008; Woyengo et al., 2008), it has been also reported that xylanase supplementation did not improve digestibility of any nutrient in growing pigs (Olukosi et al., 2007; Yáñez et al., 2011). Diebold et al. (2004) also reported no difference in ATTD of organic matter, N, EE, NDF, ADF, or GE when weaning pigs were supplemented with xylanase in a wheat-based diet. The possible reasons for this discrepancy of xylanase supplementation effect between Exp 1 and 2 could be that firstly, different amount of substrates for xylanase because Exp 1 used much lower amount of corn but greater amount of SBM in the diets than Exp 2, and the amount of corn germ meal in the diets in Exp 1 was greater by 2% than Exp 2. Diebold et al. (2004) reported that the xylanase supplementation effect may depend on the amount of target substrates and this is logical. Secondly, it could be a difference in feeding regime between Exp 1 (restricted feeding) and Exp 2 (ad libitum feeding). Chastanet et al. (2007) reported lower energy and DM digestibility in ad libitum-fed pigs compared with limit-fed pigs, and suggested that the larger quantities of feed consumption of the pigs fed ad libitum may have overwhelmed the microbes in the large intestine leading to decrease of DM and energy digestibility. Additionally, it is presumed that transit time of digesta is different by these feeding methods. Therefore, there is possibility that xylanase responses might be altered by an increased volume of digesta. Thirdly, duration of feeding treatment diets was different between the two experiments in which pigs in Exp 1 consumed the diets containing 45% of cereal by-products only during the relatively short adaptation and collection periods while pigs in Exp 2 consumed the high fiber diet containing 43% of cereal by-products for about 100 days of feeding before the digestibility assessments were made. Previously, it has been reported that NSP digestibility increased over time as pigs adapt to the dietary fiber (Longland et al., 1993), and some of volatile fatty acid concentrations in ileal digesta were increased with prolonged exposure to the high fiber diets (Chen et al., 2013). Therefore, the longer feeding duration in Exp 2 may allow microbes in the large intestine to have more adaptation time to high fiber diet compared with those in Exp 1 that in turn resulted in less effect of xylanase supplementation on nutrient digestibility. Finally, different body weight between Exp 1 (about 80 kg) and Exp 2 (about 118 kg) when fecal collection was performed might be another possible reason for the lack of effect of xylanase supplementation in Exp 2. Because natural fiber digestibility and the capacity of fiber degradation increased as body weight increased (Urriola and Stein, 2012), xylanase response in heavy pigs might be diminished compared with light pigs.

In conclusion, xylanase supplementation to the high fiber diet improved some aspects of fiber digestibility and phytase supplementation improved growth performance, carcass leanness, and digestibility of fat and fibrous components as well as P. However, the synergistic effect of combined supplementation of both xylanase and phytase was not confirmed. Furthermore, the xylanase supplementation effect may depend on dose, inclusion of fibrous ingredients (substrates), feeding duration, and body weight or age.

Table 1. Formulation and chemical composition of the experimental diet in Exp. 1 (as-fed basis)[1]

Item	Positive control	Negative control
Ingredient		
Corn	26.52	26.52
SBM (dehulled; 48% crude protein)	19.10	19.10
Corn germ meal	15.00	15.00
Corn DDGS	15.00	15.00
Wheat middlings	15.00	15.00
Corn starch	2.00	4.50
Grease	4.50	2.00
L-lysine	0.16	0.16
L-threonine	0.00	0.00
Limestone	1.55	1.55
Salt	0.50	0.50
Vitamin and trace mineral premix[2]	0.15	0.15
Santoquin	0.02	0.02
AB-20 (clay)	0.50	0.50
Total	100.00	100.00
Calculated composition, %		
ME, kcal/kg	3,360	3,256
Crude protein	21.40	21.40
Lysine	0.982	0.982
Methionine	0.376	0.376
Calcium	0.66	0.66
Total P	0.60	0.60
STTD P	0.29	0.29
Analyzed composition[3], %		
Dry matter	91.71	90.84
Gross energy, kcal/kg	4,363	4,163
Crude protein	21.97	21.60
Ether extract	6.99	4.05
Acid detergent fiber	7.57	8.02
Neutral detergent fiber	18.51	20.18
Hemicellulose	10.94	12.15
Calcium	0.77	0.66
Total P	0.62	0.62
Phytate P	0.34	0.34
Available P[4]	0.28	0.28

[1] Xylanase (Econase XT; AB vista Feed Ingredients, Marlborough, UK) was supplemented in the negative control diet at the assigned levels. All diets contained 250 FTU/kg of phytase (Quantum Blue; AB vista Feed Ingredients, Marlborough, UK)

[2] A vitamin-trace mineral premix (Akey A Sow VTM premix Se Yeast; Provimi North America, Inc., Brookville, OH). The premix supplied the following per kilogram of diet: 9,007 IU of vitamin A, 2,253 IU of vitamin D_3, 60 IU of vitamin E, 110 mg of Zn (zinc oxide), and 0.3 mg of Se (combination of sodium selenite and Se-yeast).

[3] The analyzed composition for the negative control are averaged values of Diet 2 to 5 (all diets with no additional fat). For the digestibility calculation, averaged values of all diets were used except for gross energy and fat.

[4] Available P was calculated by subtracting phytate P from total P.

Table 2. Analyzed enzyme activity of the experimental diet in Exp. 1 (as-fed basis)[1]

	Treatment[2]:	Positive control	Negative control	NX1	NX2	NX3
Items	Xylanase, BXU/kg:	0	0	8,000	16,000	24,000
Xylanase, BXU/kg		ND[3]	ND	10,800	22,300	31,800
Phytase, FTU/kg		659	565	514	542	609

[1] FTU = phytase units; BXU = xylanase unit.

[2] Treatments were 1) PC: basal diet + fat, 2) NC: basal diet, 3) NX1: basal + 8,000 BXU/kg of xylanase, 4) NX2: basal + 16,000 BXU/kg of xylanase, and 5) NX3: basal + 24,000 BXU/kg of xylanase.

[3] ND = not detected. The limit of detection was 2,000 BXU/kg.

Table 3. Formulation and chemical composition of the experimental diet in Exp. 2 (as-fed basis)[1]

Item	Phase 1		Phase 2		Phase 3		Phase 4	
	Positive control	Negative control	Positive control	Negative control	Positive control	Negative control	Positive control	Negative control
Ingredient								
Corn	27.672	27.672	33.800	33.800	38.474	38.474	43.106	43.106
SBM (dehulled, 48% CP)	21.000	21.000	15.000	15.000	10.500	10.500	6.000	6.000
Corn germ meal	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000
Corn DDGS	15.000	15.000	15.000	15.000	15.000	15.000	15.000	15.000
Wheat middlings	15.000	15.000	15.000	15.000	15.000	15.000	15.000	15.000
Corn starch	1.500	4.000	1.500	4.000	1.500	4.000	1.500	4.000
Grease	4.000	1.500	4.000	1.500	4.000	1.500	4.000	1.500
L-lysine	0.118	0.118	0.140	0.140	0.126	0.126	0.114	0.114
Limestone	1.540	1.540	1.390	1.390	1.230	1.230	1.110	1.110
Salt	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
Vit. and TM premix[2]	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150
Santoquin	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
AB-20 (clay)	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
Total	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000
Calculated composition, %								
ME, kcal/kg	3,344	3,241	3,355	3,251	3,365	3,262	3,374	3,271
Crude protein	21.90	21.90	19.56	19.56	17.78	17.78	16.01	16.01
Lysine	0.980	0.980	0.850	0.850	0.730	0.730	0.610	0.610
Methionine	0.373	0.373	0.346	0.346	0.326	0.326	0.307	0.307
Calcium	0.67	0.67	0.59	0.59	0.52	0.52	0.46	0.46
Total P	0.60	0.60	0.57	0.57	0.55	0.55	0.53	0.53
STTD P	0.29	0.29	0.28	0.28	0.27	0.27	0.26	0.26
Analyzed composition[3], %								
Dry matter	88.45	88.25	88.37	88.00	87.87	87.79	88.02	87.88
Gross energy, kcal/kg	4,112	3,965	4,114	3,930	4,072	3,939	4,110	3,984
Crude protein	22.04	22.38	20.15	20.44	17.93	18.36	16.84	16.23
Ether extract	6.94	4.55	7.31	5.02	7.33	4.54	7.28	5.23
Acid detergent fiber	7.77	7.33	7.41	7.15	7.29	7.19	8.11	7.86
Neutral detergent fiber	18.52	17.90	17.93	18.55	18.98	18.60	18.96	18.86
Hemicellulose	10.75	10.57	10.52	11.40	11.69	11.42	10.85	11.01
Calcium	0.65	0.60	0.49	0.52	0.47	0.46	0.41	0.45
Total P	0.63	0.62	0.61	0.59	0.59	0.57	0.56	0.58
Phytate P	0.45	0.40	0.40	0.37	0.40	0.38	0.37	0.40
Available P[4]	0.18	0.22	0.21	0.21	0.19	0.19	0.19	0.18

[1] Phytase (Quantum Blue; AB vista Feed Ingredients, Marlborough, UK) and xylanase (Econase XT; AB vista Feed Ingredients, Marlborough, UK) were supplemented in the negative control diet at the assigned levels.

[2] A vitamin-trace mineral premix (Akey A Sow VTM premix Se Yeast; Provimi North America, Inc., Brookville, OH). The premix supplied the following per kilogram of diet: 9,007 IU of vitamin A, 2,253 IU of vitamin D_3, 60 IU of vitamin E, 110 mg of Zn (zinc oxide), and 0.3 mg of Se (combination of sodium selenite and Se-yeast).

[3] Analyzed compositions for negative control are averaged values of Diet 2 to 9 (all diets with no additional fat). For the digestibility calculation, averaged values of all diets were used except gross energy and fat.

[4] Available P was calculated by subtracting phytate P from total P.

Table 4. Analyzed enzyme activity of the experimental diet in Exp. 2 (as-fed basis)[1]

	Treatment[2]:	PC	NC	NP500	NP1000	NP2000	NX	NXP500	NXP1000	NXP2000
	Phytase, FTU/kg:	0	0	500	1,000	2,000	0	500	1,000	2,000
Item	Xylanase, BXU/kg:	0	0	0	0	0	24,000	24,000	24,000	24,000
Phase 1										
Xylanase, BXU/kg		ND[3]	ND	ND	ND	ND	39,300	39,000	36,000	31,600
Phytase, FTU/kg		ND	ND	436	1,170	2,110	ND	492	1,120	1,620
Phase 2										
Xylanase, BXU/kg		ND	ND	ND	ND	ND	36,000	31,700	34,500	32,900
Phytase, FTU/kg		ND	ND	484	1,290	1,940	ND	706	1,220	2,490
Phase 3										
Xylanase, BXU/kg		ND	ND	ND	ND	ND	33,400	38,500	36,600	35,000
Phytase, FTU/kg		ND	ND	618	1,140	1,870	ND	551	1,070	1,950
Phase 4										
Xylanase, BXU/kg		ND	ND	ND	ND	ND	38,100	34,000	35,200	33,300
Phytase, FTU/kg		ND	ND	538	830	1,910	ND	408	955	2,260

[1] FTU = phytase units; BXU = xylanase unit.

[2] Treatments were 1) PC: basal diet + fat, 2) NC: basal diet, 3) NP500: basal + 500 FTU/kg of phytase, 4) NP1000: basal + 1,000 FTU/kg of phytase, 5) NP2000: basal + 2,000 FTU/kg of phytase, 6) NX: basal + 24,000 BXU/kg of xylanase, 7) NXP500: basal + 24,000 BXU/kg of xylanase + 500 FTU/kg of phytase, 8) NXP1000: basal + 24,000 BXU/kg of xylanase + 1,000 FTU/kg of phytase, and 9) NXP2000: basal + 24,000 BXU/kg of xylanase + 2,000 FTU/kg of phytase.

[3] ND = not detected. The limit of detection was 2,000 BXU/kg for xylanase and 50 FTU/kg for phytase, respectively.

Table 5. Apparent total tract digestibility and retention for pigs fed high by-products diets with xylanase supplementation (Exp. 1)[1]

Treatment[2]:	PC	NC	NX1	NX2	NX3		P-values[3]		
Items Xylanase, BXU/kg:	0	0	8,000	16,000	24,000	SEM	Diet	L	Q
Initial BW at adaptation, kg	77.27	77.00	76.18	76.09	76.61	0.94	0.87	0.81	0.51
Initial BW at collection, kg	79.82	78.36	78.82	78.73	79.78	1.06	0.82	0.38	0.74
Final BW, kg	84.00	82.00	82.55	81.45	83.30	1.42	0.72	0.58	0.58
Feed allowance, g/d	2,081.5	2,052.9	2,056.9	2,054.4	2,068.5	25.9	0.92	0.71	0.84
Feces excretion (dried), g/d	366.98	356.24	356.49	357.72	342.70	7.79	0.38	0.26	0.31
Urine excretion, g/d	4,531.2	4,067.4	5,103.0	4,545.9	5,565.3	386.3	0.13	**0.02**	0.93
Dry matter									
Intake, g/d	1,894.5	1,868.4	1,872.1	1,869.8	1,882.6	23.54	0.92	0.71	0.84
Excretion in feces, g/d	357.09	345.78	345.86	347.63	332.79	7.62	0.36	0.28	0.32
Digestibility, %	81.15	81.49	81.47	81.37	82.40	0.41	0.36	0.20	0.24
GE									
Intake, kcal/d	9,081.9^{a}	8,546.5^{b}	8,563.3^{b}	8,553.0^{b}	8,616.6^{b}	105.83	**0.009**	0.71	0.84
Excretion in feces, kcal/d	1,654.6	1,600.1	1,606.5	1,607.1	1,549.2	33.42	0.37	0.32	0.34
Digestibility, %	81.76	81.26	81.18	81.16	82.08	0.38	0.40	0.21	0.23
Excretion in urine, kcal/d	269.45	322.76	305.42	343.54	329.85	28.18	0.41	0.43	0.81
Retention[4], kcal/d	7,157.9^{a}	6,623.6^{b}	6,651.4^{b}	6,602.4^{b}	6,737.5^{b}	97.10	**0.004**	0.55	0.61
Retention, as % of total intake	78.79^{d}	77.48^{e}	77.60^{e}	77.22^{e}	78.23^{de}	0.41	**0.090**	0.37	0.31
Retention, as % of total absorbed	96.37	95.35	95.59	95.15	95.30	0.37	0.18	0.48	0.76
DE[5] in diet, kcal/kg	3,567.3^{a}	3,383.0^{b}	3,379.8^{b}	3,378.9^{b}	3,417.2^{b}	15.85	**<.001**	0.21	0.23
ME[6] in diet, kcal/kg	3,437.7^{a}	3,225.8^{b}	3,230.8^{b}	3,214.8^{b}	3,256.8^{b}	17.41	**<.001**	0.37	0.31
Nitrogen									
Intake, g/d	72.17	71.18	71.32	71.23	71.72	0.90	0.92	0.71	0.84
Excretion in feces, g/d	11.03	11.49	11.66	11.26	11.05	0.34	0.65	0.34	0.62
Digestibility, %	84.68	83.88	83.62	84.10	84.66	0.53	0.56	0.33	0.51
Excretion in urine, g/d	31.57	33.51	32.79	37.57	34.03	2.21	0.39	0.35	0.61
Retention, g/d	29.57	26.18	26.87	22.41	26.64	2.26	0.29	0.58	0.50
Retention, as % of total intake	40.41	36.80	37.36	32.10	36.84	2.72	0.33	0.51	0.51
Retention, as % of total absorbed	47.70	43.89	44.68	38.15	43.53	3.18	0.33	0.43	0.54
Ether extract									
Intake, g/d	145.55^{a}	83.18^{b}	83.34^{b}	83.24^{b}	84.54^{b}	1.73	**<.001**	0.71	0.84
Excretion in feces, g/d	10.55	11.31	10.94	9.99	10.72	0.88	0.86	0.58	0.59
Digestibility, %	92.71^{a}	86.38^{b}	86.78^{b}	88.06^{b}	87.33^{b}	1.08	**0.005**	0.49	0.66
Acid detergent fiber									
Intake, g/d	165.13	162.85	163.17	162.98	164.09	2.05	0.92	0.71	0.84
Excretion in feces, g/d	69.80	67.51	69.44	68.63	69.74	2.05	0.92	0.52	0.82
Digestibility, %	57.72	58.70	57.36	58.04	57.59	1.23	0.94	0.67	0.72
Neutral detergent fiber									
Intake, g/d	412.99	407.31	408.11	407.62	410.41	5.13	0.92	0.71	0.84
Excretion in feces, g/d	158.22	159.53	160.35	161.68	148.88	5.08	0.51	0.21	0.21
Digestibility, %	61.86	60.80	60.49	60.27	64.00	1.33	0.36	**0.15**	**0.16**
Hemicellulose									
Intake, g/d	247.87	244.46	244.94	244.64	246.32	3.08	0.92	0.71	0.84
Excretion in feces, g/d	88.42	92.02	90.91	93.05	79.14	4.26	0.25	**0.07**	0.14
Digestibility, %	64.62	62.19	62.58	61.76	68.27	1.89	0.18	**0.049**	**0.101**
Calcium									
Intake, g/d	14.14	13.95	13.97	13.96	14.05	0.18	0.92	0.71	0.84
Excretion in feces, g/d	8.08a	5.88^{b}	5.58^{b}	6.04^{b}	5.43^{b}	0.41	**0.002**	0.51	0.61
Digestibility, %	43.10^{b}	57.76^{a}	60.28^{a}	56.70^{a}	61.59^{a}	2.95	**0.003**	0.51	0.64
Excretion in urine, g/d	0.68	0.41	0.50	0.55	0.55	0.10	0.39	0.29	0.76
Retention, g/d	5.39^{b}	7.65^{a}	7.90^{a}	7.37^{a}	8.08^{a}	0.49	**0.009**	0.67	0.60
Retention, as % of total intake	38.34^{b}	54.88^{a}	56.94^{a}	52.83^{a}	57.85^{a}	2.93	**0.002**	0.68	0.60
Retention, as % of total absorbed	88.68^{b}	95.09^{a}	94.28^{a}	93.27^{a}	93.72^{a}	1.21	**0.013**	0.38	0.65
Phosphorus									
Intake, g/d	12.94	12.76	12.79	12.77	12.86	0.16	0.92	0.71	0.84
Excretion in feces, g/d	6.64	6.32	6.27	6.53	6.45	0.25	0.81	0.68	0.87
Digestibility, %	48.84	50.34	51.07	48.90	49.65	2.05	0.92	0.76	0.93
Excretion in urine, g/d	0.61^{c}	0.85^{b}	1.00^{a}	0.94^{ab}	1.02^{a}	0.05	**<.001**	**0.08**	0.50
Retention, g/d	5.69	5.60	5.52	5.30	5.39	0.33	0.91	0.69	0.75
Retention, as % of total intake	44.12	43.74	43.13	41.46	41.53	2.20	0.87	0.53	0.82
Retention, as % of total absorbed	90.32^{a}	86.85^{ab}	84.48^{b}	84.54^{b}	83.55^{b}	1.20	**0.008**	**0.16**	0.56

[a-c] Means within the same row without a common superscript differ ($P < 0.05$).

[d,e] Means within the same row without a common superscript differ ($P < 0.10$).

[1] Least squares means.

[2] Treatments were 1) PC: basal diet + fat, 2) NC: basal diet, 3) NX1: basal + 8,000 BXU/kg of xylanase, 4) NX2: basal + 16,000 BXU/kg of xylanase, and 5) NX3: basal + 24,000 BXU/kg of xylanase.

[3] P-values for linear (L) and quadratic (Q) responses were based on xylanase supplementation levels without PC treatment.

[4] Gross energy (GE) or nutrient (N, Ca, and P) retention (g/d) was calculated by subtracting fecal and urinary excretion of GE or nutrients from the total intake of GE and nutrients. Then, the retention was expressed in relation to the total intake (i.e., as a % of total intake) or in relation to the amount apparently absorbed (amount retained divided by [total intake minus fecal excretion]; i.e., as a % of total absorbed).

[5] Digestible energy (DE) = [GE intake (kcal/d) – Fecal GE excretion (kcal/d)]/daily feed allowance (kg/d).

[6] Metabolizable energy (ME) = [GE intake (kcal/d) – Fecal GE excretion (kcal/d) – Urinary GE excretion (kcal/d)]/daily feed allowance (kg/d).

Table 6. Daily P intake for pigs fed high by-products diets with xylanase and phytase supplementation (Exp. 2)[1,2]

Treatment[3]:	PC	NC	NP500	NP1000	NP2000	NX	NXP500	NXP1000	NXP2000	SEM	P-values[4]	
Phytase, FTU/kg:	0	0	500	1,000	2,000	0	500	1,000	2,000			
Item Xylanase, BXU/kg:	0	0	0	0	0	24,000	24,000	24,000	24,000		Treatment	PC vs. NC
Daily total P intake (calculated), g/d												
Phase 1	**9.88**	10.36	10.33	11.01	10.24	10.50	9.89	10.13	10.17	0.39	0.64	0.39
Phase 2	**12.57**	14.12	14.15	15.46	13.55	15.27	14.06	13.47	13.47	0.72	0.16	0.14
Phase 3	**15.08**	15.34	17.33	16.42	15.50	15.59	16.50	16.07	15.89	0.65	0.35	0.78
Phase 4 weight	16.55	**16.18**	18.92	17.33	16.80	16.15	17.53	17.77	17.05	0.96	0.58	0.79
Phase 4 age	16.67	**16.17**	18.94	17.57	16.97	16.26	17.60	17.82	17.15	0.98	0.63	0.72
Daily total P intake (analyzed), g/d												
Phase 1	**10.31**	10.81	10.78	11.49	10.68	10.96	10.33	10.57	10.62	0.41	0.64	0.39
Phase 2	**13.04**	14.65	14.69	16.04	14.06	15.85	14.59	13.97	13.98	0.74	0.16	0.14
Phase 3	**15.84**	16.12	18.22	17.26	16.29	16.38	17.34	16.89	16.69	0.68	0.35	0.78
Phase 4 weight	17.97	**17.57**	20.55	18.82	18.24	17.54	19.04	19.29	18.51	1.04	0.58	0.79
Phase 4 age	18.10	**17.56**	20.57	19.08	18.43	17.65	19.12	19.35	18.62	1.07	0.63	0.72
Daily STTD P intake (calculated), g/d												
Phase 1	**4.86**	5.10	5.08	5.42	5.04	5.17	4.87	4.99	5.01	0.19	0.64	0.39
Phase 2	**6.14**	6.90	6.92	7.56	6.63	7.47	6.87	6.58	6.59	0.35	0.16	0.14
Phase 3	**7.33**	7.46	8.43	7.98	7.54	7.58	8.02	7.81	7.72	0.32	0.35	0.78
Phase 4 weight	8.00	**7.82**	9.14	8.37	8.11	7.80	8.47	8.58	8.24	0.46	0.58	0.79
Phase 4 age	8.05	**7.81**	9.15	8.49	8.20	7.85	8.50	8.61	8.29	0.48	0.63	0.72

[1] Phosphorus intake was calculated by multiplying ADFI with either calculated or analyzed dietary P content in each phase. Daily total P requirement were 8.47, 10.92, 11.86 and 11.97 g/d (4.59, 5.78, 6.11, and 5.95 g/d STTD P) for 25-50 kg (Phase 1), 50-75 kg (Phase 2), 75-100 kg (Phase 3), and 100-135 kg (Phase 4), respectively (NRC, 2012).

[2] Least squares means.

[3] Treatments were 1) PC: basal diet + fat, 2) NC: basal diet, 3) NP500: basal + 500 FTU/kg of phytase, 4) NP1000: basal + 1,000 FTU/kg of phytase, 5) NP2000: basal + 2,000 FTU/kg of phytase, 6) NX: basal + 24,000 BXU/kg of xylanase, 7) NXP500: basal + 24,000 BXU/kg of xylanase + 500 FTU/kg of phytase, 8) NXP1000: basal + 24,000 BXU/kg of xylanase + 1,000 FTU/kg of phytase, and 9) NXP2000: basal + 24,000 BXU/kg of xylanase + 2,000 FTU/kg of phytase.

[4] P-values are for the overall treatment effect and a single degree of freedom contrast between PC and NC treatments.

Table 7. Growth performance for pigs fed high by-products diets with xylanase and phytase supplementation (individual treatment effects; Exp. 2)[1]

Treatment[2]:	PC	NC	NP500	NP1000	NP2000	NX	NXP500	NXP1000	NXP2000	SEM	P-values[3]	
Phytase, FTU/kg:	0	0	500	1,000	2,000	0	500	1,000	2,000			
Item Xylanase, BXU/kg:	0	0	0	0	0	24,000	24,000	24,000	24,000		Treatment	PC vs. NC
Day at the end of												
Phase 1	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	0.00	.	.
Phase 2	56.00	56.00	56.00	56.00	56.00	56.00	56.00	56.00	56.00	0.00	.	.
Phase 3	81.20	81.20	81.20	81.20	81.20	81.20	81.20	81.20	81.20	0.00	.	.
Phase 4 common weight	106.40	109.20	105.00	105.00	106.40	109.20	105.00	105.00	106.40	1.11	**0.04**	**0.08**
Phase 4 common age	105.00	105.00	105.00	105.00	105.00	105.00	105.00	105.00	105.00	0.00	.	.
Duration, d												
Phase 1	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	0.00	.	.
Phase 2	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	0.00	.	.
Phase 3	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20	25.20	0.00	.	.
Phase 4 common weight	25.20	28.00	23.80	23.80	25.20	28.00	23.80	23.80	25.20	1.11	**0.04**	**0.08**
Phase 4 common age	23.80	23.80	23.80	23.80	23.80	23.80	23.80	23.80	23.80	0.00	.	.
Body weight, kg												
Initial	26.27	26.27	26.27	26.73	26.09	26.36	26.64	26.36	26.36	0.33	0.93	1.00
Phase 1	49.55	49.45	50.27	51.82	50.09	50.36	50.18	50.73	49.09	0.74	0.34	0.93
Phase 2	74.73^{efg}	73.27^{g}	77.27^{de}	78.45^{d}	76.00^{defg}	75.18^{efg}	76.64^{def}	76.45^{def}	74.18^{fg}	1.15	**0.08**	0.38
Phase 3	99.27	94.91	99.36	101.91	99.36	97.91	101.09	99.64	98.18	1.64	0.20	**0.07**
Phase 4 common weight	123.27	117.82	122.09	124.36	120.91	119.55	123.45	123.55	122.00	2.26	0.54	**0.10**
Phase 4 common age	122.27	114.64	122.09	124.36	120.18	117.18	123.45	123.55	121.27	2.56	0.17	**0.04**
ADG, kg/d												
Phase 1	0.831	0.828	0.857	0.896	0.857	0.857	0.841	0.870	0.812	0.024	0.39	0.92
Phase 2	0.899	0.851	0.964	0.951	0.925	0.886	0.945	0.919	0.896	0.028	0.14	0.22
Phase 3	0.981	0.864	0.881	0.936	0.930	0.905	0.976	0.922	0.965	0.040	0.41	**0.05**
Phase 4 common weight	0.955	0.828	0.962	0.941	0.868	0.773	0.925	0.985	0.945	0.055	0.14	0.11
Phase 4 common age	0.962	0.827	0.962	0.941	0.874	0.811	0.925	0.985	0.960	0.053	0.22	**0.08**
Overall common weight	0.913	0.840	0.913	0.930	0.893	0.854	0.922	0.926	0.900	0.025	0.16	**0.05**
Overall common age	0.914	0.842	0.913	0.930	0.896	0.865	0.922	0.926	0.904	0.024	0.19	**0.04**
ADFI, kg/d												
Phase 1	1.660	1.741	1.735	1.849	1.720	1.765	1.662	1.702	1.710	0.066	0.64	0.39
Phase 2	2.210	2.484	2.490	2.720	2.384	2.686	2.473	2.369	2.370	0.126	0.16	0.14
Phase 3	2.748	2.796	3.159	2.993	2.826	2.841	3.008	2.929	2.895	0.119	0.35	0.78
Phase 4 common weight	3.130	3.060	3.579	3.278	3.177	3.055	3.316	3.360	3.224	0.181	0.58	0.79
Phase 4 common age	3.152	3.059	3.583	3.322	3.210	3.074	3.329	3.370	3.243	0.186	0.63	0.72
Overall common weight	2.410	2.509	2.685	2.679	2.494	2.577	2.579	2.553	2.518	0.089	0.47	0.44
Overall common age	2.400	2.487	2.685	2.679	2.488	2.557	2.579	2.553	2.512	0.091	0.44	0.50
G:F ratio												
Phase 1	0.502	0.476	0.497	0.487	0.499	0.486	0.508	0.514	0.475	0.015	0.59	0.24
Phase 2	0.407	0.353	0.388	0.359	0.390	0.339	0.383	0.394	0.378	0.017	0.16	**0.04**
Phase 3	0.356^{a}	0.310^{bc}	0.281^{c}	0.317^{bc}	0.329^{ab}	0.320^{ab}	0.325^{ab}	0.318^{bc}	0.332^{ab}	0.013	**0.04**	**0.02**
Phase 4 common weight	0.304	0.271	0.274	0.287	0.272	0.253	0.279	0.292	0.292	0.012	0.17	**0.06**
Phase 4 common age	0.305	0.271	0.274	0.284	0.272	0.264	0.278	0.292	0.296	0.012	0.29	**0.05**
Overall common weight	0.379^{d}	0.336^{fg}	0.341^{efg}	0.349^{efg}	0.358^{def}	0.333^{g}	0.358^{def}	0.365^{de}	0.357^{defg}	0.011	**0.09**	**0.01**
Overall common age	0.381	0.340	0.341	0.349	0.361	0.340	0.358	0.365	0.360	0.010	0.11	**0.01**

[a-c]Means within the same row without a common superscript differ ($P < 0.05$). [d-g]Means within the same row without a common superscript differ ($P < 0.10$).

[1] Least squares means.

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[2] Treatments were 1) PC: basal diet + fat, 2) NC: basal diet, 3) NP500: basal + 500 FTU/kg of phytase, 4) NP1000: basal + 1,000 FTU/kg of phytase, 5) NP2000: basal + 2,000 FTU/kg of phytase, 6) NX: basal + 24,000 BXU/kg of xylanase, 7) NXP500: basal + 24,000 BXU/kg of xylanase + 500 FTU/kg of phytase, 8) NXP1000: basal + 24,000 BXU/kg of xylanase + 1,000 FTU/kg of phytase, and 9) NXP2000: basal + 24,000 BXU/kg of xylanase + 2,000 FTU/kg of phytase.

[3] P-values are for the overall treatment effect and a single degree of freedom contrast between PC and NC treatments.

Table 8. Growth performance for pigs fed high by-products diets with xylanase and phytase supplementation (main effects; Exp. 2)[1]

	Xylanase, BXU/kg			Phytase levels, FTU/kg					P-values[2]			
Item	0	24,000	SEM	0	500	1,000	2,000	SEM	Xylanase	Phytase	L	Q
Day at the end of												
Phase 1	28.00	28.00	-	28.00	28.00	28.00	28.00	-	-	-	-	-
Phase 2	56.00	56.00	-	56.00	56.00	56.00	56.00	-	-	-	-	-
Phase 3	81.20	81.20	-	81.20	81.20	81.20	81.20	-	-	-	-	-
Phase 4 common weight	106.40	106.40	0.54	109.20	105.00	105.00	106.40	0.77	1.00	**0.002**	0.07	**0.001**
Phase 4 common age	105.00	105.00	-	105.00	105.00	105.00	105.00	-	-	-	-	-
Duration, d												
Phase 1	28.00	28.00	-	28.00	28.00	28.00	28.00	-	-	-	-	-
Phase 2	28.00	28.00	-	28.00	28.00	28.00	28.00	-	-	-	-	-
Phase 3	25.20	25.20	-	25.20	25.20	25.20	25.20	-	-	-	-	-
Phase4 common weight	25.20	25.20	0.54	28.00	23.80	23.80	25.20	0.77	1.00	**0.002**	0.07	**0.001**
Phase 4 common age	23.80	23.80	-	23.80	23.80	23.80	23.80	-	-	-	-	-
Body weight, kg												
Initial	26.34	26.43	0.17	26.32	26.45	26.55	26.23	0.24	0.71	0.79	0.73	0.35
Phase 1	50.41	50.09	0.37	**49.91**	**50.23**	**51.27**	**49.59**	**0.53**	0.55	0.15	0.70	**0.05**
Phase 2	76.25	75.61	0.60	**74.23**	**76.95**	**77.45**	**75.09**	**0.85**	0.46	**0.04**	0.78	**0.01**
Phase 3	98.89	99.20	0.82	**96.41**	**100.23**	**100.77**	**98.77**	**1.15**	0.78	**0.05**	0.31	**0.01**
Phase 4 common weight	121.30	122.14	1.17	**118.68**	**122.77**	**123.95**	**121.45**	**1.66**	0.62	0.16	0.37	**0.04**
Phase 4 common age	120.32	121.36	1.30	**115.91**	**122.77**	**123.95**	**120.73**	**1.83**	0.57	**0.02**	0.17	**0.01**
ADG, kg/d												
Phase 1	0.860	0.845	0.012	**0.843**	**0.849**	**0.883**	**0.834**	**0.016**	0.38	0.19	0.79	**0.06**
Phase 2	0.923	0.912	0.014	**0.869**	**0.955**	**0.935**	**0.911**	**0.020**	0.58	**0.03**	0.44	**0.01**
Phase 3	0.903	0.942	0.020	0.884	0.929	0.929	0.948	0.028	0.17	0.44	0.15	0.53
Phase 4 common weight	0.900	0.907	0.028	**0.800**	**0.944**	**0.963**	**0.906**	**0.040**	0.85	**0.03**	0.16	**0.01**
Phase 4 common age	0.901	0.920	0.028	**0.819**	**0.944**	**0.963**	**0.917**	**0.039**	0.63	**0.07**	0.17	**0.02**
Overall common weight	0.894	0.901	0.013	**0.847**	**0.917**	**0.928**	**0.897**	**0.018**	0.71	**0.02**	0.15	**0.01**
Overall common age	0.895	0.904	0.012	**0.853**	**0.917**	**0.928**	**0.900**	**0.017**	0.60	**0.03**	0.15	**0.01**
ADFI, kg/d												
Phase 1	1.761	1.710	0.034	1.753	1.699	1.776	1.715	0.048	0.29	0.66	0.78	0.79
Phase 2	2.519	2.475	0.065	2.585	2.482	2.544	2.377	0.092	0.63	0.42	0.15	0.79
Phase 3	2.944	2.918	0.060	**2.818**	**3.084**	**2.961**	**2.861**	**0.085**	0.77	0.15	0.79	**0.07**
Phase 4 common weight	3.273	3.239	0.096	**3.057**	**3.447**	**3.319**	**3.200**	**0.135**	0.80	0.23	0.81	**0.09**
Phase 4 common age	3.293	3.254	0.098	**3.066**	**3.456**	**3.346**	**3.227**	**0.139**	0.78	0.25	0.74	**0.09**
Overall common weight	2.592	2.557	0.047	2.543	2.632	2.616	2.506	0.066	0.60	0.50	0.51	0.18
Overall common age	2.585	2.550	0.048	2.522	2.632	2.616	2.500	0.067	0.61	0.42	0.59	0.13
G:F ratio												
Phase 1	0.490	0.496	0.008	0.481	0.502	0.501	0.487	0.011	0.59	0.45	0.94	0.13
Phase 2	0.373	0.374	0.009	**0.346**	**0.386**	**0.377**	**0.384**	**0.012**	0.93	0.11	**0.10**	0.18
Phase 3	0.309	0.324	0.006	0.315	0.303	0.317	0.330	0.009	0.12	0.22	0.11	0.35
Phase 4 common weight	0.276	0.279	0.006	0.262	0.277	0.290	0.282	0.009	0.72	0.19	0.13	0.12
Phase 4 common age	0.275	0.282	0.006	0.267	0.276	0.288	0.284	0.009	0.42	0.40	0.19	0.31
Overall common weight	0.346	0.353	0.005	**0.334**	**0.350**	**0.357**	**0.358**	**0.007**	0.35	0.12	**0.04**	0.18
Overall common age	0.348	0.356	0.005	**0.340**	**0.350**	**0.357**	**0.360**	**0.007**	0.29	0.23	**0.06**	0.40

[1] Least squares means.

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[2] P-values for linear (L) and quadratic (Q) responses were based on phytase supplementation levels. There was no interaction between xylanase and phytase supplementation ($P > 0.22$).

Table 9. Carcass characteristics for pigs fed high by-products diets with xylanase and phytase supplementation (individual treatment effects with scan weight as a covariate; Exp. 2)[1]

Treatment[2]:	PC	NC	NP500	NP1000	NP2000	NX	NXP500	NXP1000	NXP2000	SEM	P-values[3]	
Phytase, FTU/kg:	0	0	500	1,000	2,000	0	500	1,000	2,000			
Item Xylanase, BXU/kg:	0	0	0	0	0	24,000	24,000	24,000	24,000		Treatment	PC vs. NC
Common weight basis												
Scan weight[4], kg	121.89	121.89	121.89	121.89	121.89	121.89	121.89	121.89	121.89	-	-	-
Backfat, mm	13.74	15.59	16.59	14.69	15.65	17.91	14.93	14.52	15.19	1.08	0.31	0.25
Longissimus muscle depth, mm	62.61	60.35	60.97	63.27	66.93	64.51	60.79	60.38	62.79	2.92	0.78	0.60
Longissimus area, %	41.66	40.30	40.68	42.05	44.25	42.80	40.57	40.32	41.76	1.75	0.78	0.60
Carcass lean, %	57.61	56.23	55.70	57.12	56.97	55.33	56.68	56.87	56.76	0.80	0.64	0.25
Initial lean, kg	9.31	9.35	9.32	9.50	9.25	9.38	9.46	9.35	9.36	0.14	0.97	0.85
Final lean, kg	47.85	46.79	46.63	47.72	48.28	47.06	47.08	47.11	47.46	0.81	0.88	0.37
Lean gain, g/d	362.06	345.16	355.26	362.92	367.91	346.62	357.56	358.85	358.38	7.66	0.55	0.14
Lean gain/feed	0.152	0.134	0.133	0.139	0.147	0.133	0.141	0.144	0.142	0.006	0.42	**0.06**
Common age basis												
Scan weight[4], kg	121.00	121.00	121.00	121.00	121.00	121.00	121.00	121.00	121.00	-	-	-
Backfat, mm	13.88	15.59	16.50	14.49	14.88	17.55	14.77	14.36	14.77	1.04	0.35	0.28
Longissimus muscle depth, mm	61.97	59.15	60.80	62.99	66.55	60.89	60.56	60.14	60.15	2.55	0.63	0.46
Longissimus area, %	41.28	39.59	40.58	41.89	44.02	40.63	40.43	40.18	40.19	1.53	0.63	0.46
Carcass lean, %	57.45	56.09	55.74	57.20	57.39	55.12	56.75	56.94	56.70	0.75	0.41	0.23
Initial lean, kg	9.31	9.37	9.31	9.49	9.25	9.39	9.46	9.34	9.36	0.14	0.97	0.78
Final lean, kg	47.40	46.25	46.36	47.46	48.16	46.07	46.82	46.84	46.72	0.71	0.55	0.28
Lean gain, g/d	362.76	351.24	352.85	361.64	370.51	349.34	355.82	357.16	355.85	6.87	0.52	0.27
Lean gain/feed	0.152	0.136	0.133	0.140	0.149	0.134	0.141	0.144	0.142	0.006	0.29	**0.06**

[1] Least squares means.

[2] Treatments were 1) PC: basal diet + fat, 2) NC: basal diet, 3) NP500: basal + 500 FTU/kg of phytase, 4) NP1000: basal + 1,000 FTU/kg of phytase, 5) NP2000: basal + 2,000 FTU/kg of phytase, 6) NX: basal + 24,000 BXU/kg of xylanase, 7) NXP500: basal + 24,000 BXU/kg of xylanase + 500 FTU/kg of phytase, 8) NXP1000: basal + 24,000 BXU/kg of xylanase + 1,000 FTU/kg of phytase, and 9) NXP2000: basal + 24,000 BXU/kg of xylanase + 2,000 FTU/kg of phytase.

[3] P-values are for the overall treatment effect and a single degree of freedom contrast between PC and NC treatments. There was no interaction between xylanase and phytase supplementation (P > 0.34).

[4] Because scan weight on both a weight and an age basis was significantly different with phytase supplementation, scan weight was used as a covariate.

Table 10. Carcass characteristics for pigs fed high by-products diets with xylanase and phytase supplementation (main effects with scan weight as a covariate; Exp. 2)[1]

	Xylanase, BXU/kg			Phytase levels, FTU/kg					P-values[2]			
Item	0	24,000	SEM	0	500	1,000	2,000	SEM	Xylanase	Phytase	L	Q
Common weight basis												
Scan weight[3], kg	121.72	121.72	-	121.72	121.72	121.72	121.72	-	-	-	-	-
Backfat, mm	15.62	15.63	0.55	16.76	15.74	14.58	15.41	0.79	0.99	0.34	0.24	0.17
Longissimus muscle depth, mm	62.81	62.14	1.40	62.06	60.98	62.06	64.80	2.02	0.74	0.57	0.25	0.50
Longissimus area, %	41.78	41.38	0.84	41.33	40.68	41.33	42.97	1.21	0.74	0.57	0.25	0.50
Carcass lean, %	56.50	56.42	0.40	55.73	56.21	57.04	56.86	0.58	0.89	0.40	0.15	0.39
Initial lean, kg	9.35	9.39	0.07	9.36	9.39	9.42	9.31	0.10	0.75	0.88	0.66	0.53
Final lean, kg	47.29	47.14	0.39	46.78	46.83	47.42	47.81	0.57	0.78	0.52	0.16	0.98
Lean gain, g/d	357.09	354.92	3.67	**344.28**	**356.20**	**361.08**	**362.48**	5.30	0.68	0.10	**0.03**	0.20
Lean gain/feed	0.138	0.140	0.003	0.133	0.137	0.142	0.145	0.004	0.65	0.28	**0.06**	0.60
Common age basis												
Scan weight[3], kg	120.84	120.84	-	120.84	120.84	120.84	120.84	-	-	-	-	-
Backfat, mm	15.35	15.35	0.52	**16.61**	**15.60**	**14.38**	**14.81**	0.77	0.99	0.26	**0.10**	0.23
Longissimus muscle depth, mm	62.29	60.46	1.17	59.49	60.85	61.86	63.31	1.74	0.28	0.47	0.12	0.82
Longissimus area, %	41.47	40.37	0.70	39.79	40.60	41.21	42.08	1.04	0.28	0.47	0.12	0.82
Carcass lean, %	56.60	56.39	0.36	**55.52**	**56.28**	**57.14**	**57.05**	0.53	0.68	0.17	**0.05**	0.26
Initial lean, kg	9.36	9.39	0.07	9.38	9.38	9.41	9.30	0.11	0.77	0.89	0.61	0.65
Final lean, kg	47.00	46.58	0.33	**45.98**	**46.59**	**47.18**	**47.39**	0.49	0.38	0.22	**0.04**	0.45
Lean gain, g/d	358.48	354.22	3.19	**348.60**	**354.37**	**359.73**	**362.70**	4.71	0.35	0.20	**0.04**	0.52
Lean gain/feed	0.139	0.140	0.003	0.134	0.137	0.142	0.145	0.004	0.76	0.23	**0.05**	0.64

[1] Least squares means.

[2] P-values for linear (L) and quadratic (Q) responses were based on phytase supplementation levels. There was no interaction between xylanase and phytase supplementation (P > 0.34).

[3] Because scan weight on both a weight and an age basis was significantly different with phytase supplementation, scan weight was used as a covariate.

Table 11. Apparent total tract digestibility (%) for pigs fed high by-products diets with xylanase and phytase supplementation in Phase 4 (individual treatment effects; Exp. 2)[1]

	Treatment[2]:	PC	NC	NP500	NP1000	NP2000	NX	NXP500	NXP1000	NXP2000	SEM	P-values[3]	
	Phytase, FTU/kg:	0	0	500	1,000	2,000	0	500	1,000	2,000			
Item	Xylanase, BXU/kg:	0	0	0	0	0	24,000	24,000	24,000	24,000		Treatment	PC vs. NC
Dry matter		**76.84^{d}**	**77.74^{bcd}**	**79.38^{a}**	**78.60^{abc}**	**78.59^{abc}**	**77.41^{cd}**	**78.85^{ab}**	**79.05^{ab}**	**78.84^{ab}**	0.48	**0.01**	0.20
Energy		76.84	77.38	78.98	77.68	78.00	76.83	78.15	78.20	78.30	0.56	0.17	0.50
Nitrogen		74.12	75.24	77.19	76.63	75.92	74.86	76.64	76.24	77.10	0.93	0.28	0.40
Ether extract		**76.64^{a}**	**66.21^{bc}**	**74.58^{a}**	**75.90^{abc}**	**69.74^{abc}**	**63.80^{bc}**	**71.97^{abc}**	**73.67^{ab}**	**70.82^{abc}**	2.88	**0.05**	**0.02**
Acid detergent fiber		50.07	49.52	53.53	53.40	51.28	50.10	50.26	50.45	52.00	1.83	0.72	0.83
Neutral detergent fiber		**49.33^{c}**	**50.38^{bc}**	**55.56^{a}**	**52.40^{abc}**	**54.12^{a}**	**50.32^{bc}**	**53.56^{ab}**	**54.13^{a}**	**52.69^{ab}**	1.15	**0.01**	0.52
Hemicellulose		**48.80^{c}**	**50.99^{bc}**	**57.03^{a}**	**51.68^{abc}**	**56.15^{ab}**	**50.48^{c}**	**55.92^{ab}**	**56.76^{a}**	**53.19^{abc}**	1.87	**0.02**	0.41
Calcium		44.25	46.75	45.17	47.28	43.37	46.92	43.29	49.48	51.64	2.95	0.52	0.55
Phosphorus		**35.52^{f}**	**42.66^{de}**	**45.20^{cde}**	**53.41^{abc}**	**50.08^{abc}**	**40.40^{ef}**	**47.24^{bcd}**	**47.26^{bcd}**	**52.88^{ab}**	2.05	**<.0001**	**0.02**

[a-f] Means within the same row without a common superscript differ ($P < 0.05$).

[1] Least squares means.

[2] Treatments were 1) PC: basal diet + fat, 2) NC: basal diet, 3) NP500: basal + 500 FTU/kg of phytase, 4) NP1000: basal + 1,000 FTU/kg of phytase, 5) NP2000: basal + 2,000 FTU/kg of phytase, 6) NX: basal + 24,000 BXU/kg of xylanase, 7) NXP500: basal + 24,000 BXU/kg of xylanase + 500 FTU/kg of phytase, 8) NXP1000: basal + 24,000 BXU/kg of xylanase + 1,000 FTU/kg of phytase, and 9) NXP2000: basal + 24,000 BXU/kg of xylanase + 2,000 FTU/kg of phytase.

[3] P-values are for the treatment effect and a single degree of freedom contrast between PC and NC treatments. There was no interaction between xylanase and phytase supplementation ($P > 0.14$).

Table 12. Apparent total tract digestibility (%) for pigs fed high by-products diets with xylanase and phytase supplementation in Phase 4 (main effects; Exp. 2)[1]

	Xylanase, BXU/kg			Phytase levels, FTU/kg					P-values[2]			
Item	0	24,000	SEM	0	500	1,000	2,000	SEM	Xylanase	Phytase	L	Q
Dry matter	78.58	78.54	0.24	**77.57**	**79.12**	**78.82**	**78.71**	0.34	0.91	**0.02**	**0.10**	**0.02**
Energy	78.01	77.87	0.28	**77.11**	**78.56**	**77.94**	**78.15**	0.40	0.73	**0.09**	0.22	0.15
Nitrogen	76.24	76.21	0.46	75.05	76.91	76.44	76.51	0.66	0.96	0.23	0.26	0.18
Ether extract	71.61	70.60	1.48	**65.01**	**73.28**	**74.79**	**70.28**	2.09	0.46	0.013	**0.20**	**<0.01**
Acid detergent fiber	51.93	50.70	0.91	49.81	51.89	51.92	51.64	1.28	0.35	0.61	0.42	0.32
Neutral detergent fiber	53.12	52.67	0.56	**50.35**	**54.56**	**53.26**	**53.41**	0.79	0.58	**0.01**	**0.07**	**0.01**
Hemicellulose	53.96	54.09	0.87	**50.74**	**56.47**	**54.22**	**54.67**	1.23	0.92	**0.02**	0.15	**0.05**
Calcium	45.64	47.83	1.52	46.83	44.23	48.38	47.50	2.15	0.32	0.57	0.55	0.96
Phosphorus	47.84	46.94	1.05	**41.53**	**46.22**	**50.34**	**51.48**	1.49	0.55	**<.001**	**<.001**	**0.04**

[1] Least squares means.

[2] P-values for linear (L) and quadratic (Q) responses were based on phytase supplementation levels. There was no interaction between xylanase and phytase supplementation ($P > 0.14$).

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Appendices

Appendix 1. Growth performance for pigs fed high by-products diets with only phytase supplementation (Exp. 2)[1]

Treatment[2]:	PC	NC	NP500	NP1000	NP2000		
Phytase, FTU/kg:	0	0	500	1,000	2,000	SEM	P-values
Item Xylanase, BXU/kg:	0	0	0	0	0		
Day at the end of							
Phase 1	28.00	28.00	28.00	28.00	28.00	.	.
Phase 2	56.00	56.00	56.00	56.00	56.00	.	.
Phase 3	81.20	81.20	81.20	81.20	81.20	.	.
Phase 4 common weight	106.40	109.20	105.00	105.00	106.40	1.11	0.09
Phase 4 common age	105.00	105.00	105.00	105.00	105.00	.	.
Duration, d							
Phase 1	28.00	28.00	28.00	28.00	28.00	.	.
Phase 2	28.00	28.00	28.00	28.00	28.00	.	.
Phase 3	25.20	25.20	25.20	25.20	25.20	.	.
Phase4 common weight	25.20	28.00	23.80	23.80	25.20	1.11	0.09
Phase 4 common age	23.80	23.80	23.80	23.80	23.80	.	.
Body weight, kg							
Initial	26.27	26.27	26.27	26.73	26.09	0.35	0.76
Phase 1	49.55	49.45	50.27	51.82	50.09	0.73	0.20
Phase 2	**74.73**^{ef}	**73.27**^{f}	**77.27**^{de}	**78.45**^{d}	**76.00**^{def}	1.31	**0.09**
Phase 3	**99.27**^{d}	**94.91**^{e}	**99.36**^{d}	**101.91**^{d}	**99.36**^{d}	1.59	**0.08**
Phase 4 common weight	123.27	117.82	122.09	124.36	120.91	2.34	0.36
Phase 4 common age	122.27	114.64	122.09	124.36	120.18	2.72	0.17
ADG, kg							
Phase 1	0.831	0.828	0.857	0.896	0.857	0.023	0.27
Phase 2	0.899	0.851	0.964	0.951	0.925	0.033	0.17
Phase 3	0.981	0.864	0.881	0.936	0.930	0.035	0.18
Phase 4 common weight	0.955	0.828	0.962	0.941	0.868	0.058	0.42
Phase 4 common age	0.962	0.827	0.962	0.941	0.874	0.057	0.38
Overall common weight	0.913	0.840	0.913	0.930	0.893	0.026	0.19
Overall common age	0.914	0.842	0.913	0.930	0.896	0.026	0.18
ADFI, kg							
Phase 1	1.660	1.741	1.735	1.849	1.720	0.070	0.45
Phase 2	**2.210**^{e}	**2.484**^{de}	**2.490**^{de}	**2.720**^{d}	**2.384**^{e}	0.114	**0.07**
Phase 3	2.748	2.796	3.159	2.993	2.826	0.132	0.21
Phase 4 common weight	3.130	3.060	3.579	3.278	3.177	0.211	0.47
Phase 4 common age	3.152	3.059	3.583	3.322	3.210	0.220	0.52
Overall common weight	2.410	2.509	2.685	2.679	2.494	0.086	0.14
Overall common age	2.400	2.487	2.685	2.679	2.488	0.088	0.13
G:F ratio							
Phase 1	0.502	0.476	0.497	0.487	0.499	0.014	0.71
Phase 2	0.407	0.353	0.388	0.359	0.390	0.017	0.19
Phase 3	**0.356**^{a}	**0.310**^{bc}	**0.281**^{c}	**0.317**^{abc}	**0.329**^{ab}	0.014	**0.02**
Phase 4 common weight	0.304	0.271	0.274	0.287	0.272	0.015	0.46
Phase 4 common age	0.305	0.271	0.274	0.284	0.272	0.015	0.45
Overall common weight	0.379	0.336	0.341	0.349	0.358	0.013	0.18
Overall common age	0.381	0.340	0.341	0.349	0.361	0.012	0.14

$^{a\text{-}c}$Means within the same row without a common superscript differ ($P < 0.05$).

$^{d\text{-}f}$Means within the same row without a common superscript differ ($P < 0.10$).

[1] Least squares means.

[2] Treatments were 1) PC: basal diet + fat, 2) NC: basal diet, 3) NP500: basal + 500 FTU/kg of phytase, 4) NP1000: basal + 1,000 FTU/kg of phytase, and 5) NP2000: basal + 2,000 FTU/kg of phytase.

Appendix 2. Growth performance for pigs fed high by-products diets with only xylanase supplementation (Exp. 2)[1]

	Treatment[2]:	PC	NC	NX	SEM	P-values
	Phytase, FTU/kg:	0	0	0		
Item	Xylanase, BXU/kg:	0	0	24,000		
Day at the end of						
Phase 1		28.00	28.00	28.00	.	.
Phase 2		56.00	56.00	56.00	.	.
Phase 3		81.20	81.20	81.20	.	.
Phase 4 common weight		106.40	109.20	109.20	1.34	0.29
Phase 4 common age		105.00	105.00	105.00	.	.
Duration, d						
Phase 1		28.00	28.00	28.00	.	.
Phase 2		28.00	28.00	28.00	.	.
Phase 3		25.20	25.20	25.20	.	.
Phase4 common weight		25.20	28.00	28.00	1.34	0.29
Phase 4 common age		23.80	23.80	23.80	.	.
Body weight, kg						
Initial		26.27	26.27	26.36	0.27	0.96
Phase 1		49.55	49.45	50.36	0.75	0.65
Phase 2		74.73	73.27	75.18	0.93	0.36
Phase 3		99.27	94.91	97.91	1.27	0.10
Phase 4 common weight		**123.27^{a}**	**117.82^{b}**	**119.55^{ab}**	1.19	**0.03**
Phase 4 common age		**122.27^{a}**	**114.64^{b}**	**117.18^{ab}**	1.69	**0.03**
ADG, kg						
Phase 1		0.831	0.828	0.857	0.027	0.71
Phase 2		**0.899^{c}**	**0.851^{d}**	**0.886^{cd}**	0.014	**0.10**
Phase 3		**0.981^{c}**	**0.864^{d}**	**0.905^{cd}**	0.033	**0.09**
Phase 4 common weight		**0.955^{a}**	**0.828^{b}**	**0.773^{b}**	0.037	**0.02**
Phase 4 common age		**0.962^{a}**	**0.827^{b}**	**0.811^{b}**	0.036	**0.03**
Overall common weight		**0.913^{a}**	**0.840^{b}**	**0.854^{ab}**	0.018	**0.05**
Overall common age		**0.914^{a}**	**0.842^{b}**	**0.865^{ab}**	0.017	**0.04**
ADFI, kg						
Phase 1		1.660	1.741	1.765	0.048	0.32
Phase 2		2.210	2.484	2.686	0.142	0.12
Phase 3		2.748	2.796	2.841	0.072	0.65
Phase 4 common weight		3.130	3.060	3.055	0.044	0.44
Phase 4 common age		3.152	3.059	3.074	0.065	0.57
Overall common weight		2.410	2.509	2.577	0.053	0.14
Overall common age		2.400	2.487	2.557	0.055	0.19
G:F ratio						
Phase 1		0.502	0.476	0.486	0.014	0.45
Phase 2		**0.407^{a}**	**0.353^{ab}**	**0.339^{b}**	0.017	**0.05**
Phase 3		**0.356^{c}**	**0.310^{d}**	**0.320^{d}**	0.013	**0.07**
Phase 4 common weight		**0.304^{a}**	**0.271^{ab}**	**0.253^{b}**	0.011	**0.03**
Phase 4 common age		**0.305^{a}**	**0.271^{b}**	**0.264^{b}**	0.009	**0.03**
Overall common weight		**0.379^{a}**	**0.336^{b}**	**0.333^{b}**	0.010	**0.02**
Overall common age		**0.381^{a}**	**0.340^{b}**	**0.340^{b}**	0.009	**0.02**

[a,b] Means within the same row without a common superscript differ ($P < 0.05$).

[c,d] Means within the same row without a common superscript differ ($P < 0.10$).

[1] Least squares means.

[2] Treatments were 1) PC: basal diet + fat, 2) NC: basal diet, and 3) NX: basal + 24,000 BXU/kg of xylanase.

Appendix 3. Carcass characteristics for pigs fed high by-products diets with only phytase supplementation (using scan weight as a covariate; Exp. 2)[1]

	Treatment[2]:	PC	NC	NP500	NP1000	NP2000		
	Phytase, FTU/kg:	0	0	500	1,000	2,000	SEM	P-values
Item	Xylanase, BXU/kg:	0	0	0	0	0		
Common weight basis								
Scan weight[3], kg		121.69	121.69	121.69	121.69	121.69	-	-
Backfat, mm		13.63	15.82	16.56	14.51	15.68	1.16	0.44
Longissimus muscle depth, mm		61.79	62.28	60.74	61.89	67.30	2.34	0.33
Longissimus area, %		41.17	41.46	40.54	41.23	44.47	1.40	0.33
Carcass lean, %		57.58	56.32	55.70	57.06	56.99	0.81	0.53
Initial lean, kg		9.30	9.37	9.32	9.48	9.26	0.15	0.85
Final lean, kg		47.64	47.10	46.53	47.40	48.29	0.71	0.49
Lean gain, g/d		359.78	348.47	354.20	359.52	368.05	7.19	0.42
Lean gain/feed		0.150	0.138	0.133	0.136	0.148	0.006	0.25
Common age basis								
Scan weight[3], kg		120.71	120.71	120.71	120.71	120.71	-	-
Backfat, mm		13.79	15.82	16.41	14.30	14.87	1.09	0.44
Longissimus muscle depth, mm		61.39	61.15	60.28	61.71	66.67	2.44	0.36
Longissimus area, %		40.93	40.78	40.27	41.12	44.09	1.46	0.36
Carcass lean, %		57.43	56.18	55.73	57.16	57.41	0.80	0.44
Initial lean, kg		9.31	9.38	9.31	9.48	9.25	0.15	0.85
Final lean, kg		47.21	46.56	46.19	47.13	48.10	0.73	0.40
Lean gain, g/d		361.01	354.04	351.20	358.63	370.01	7.32	0.41
Lean gain/feed		0.151	0.140	0.132	0.137	0.149	0.007	0.20

[1] Least squares means.

[2] Treatments were 1) PC: basal diet + fat, 2) NC: basal diet, 3) NP500: basal + 500 FTU/kg of phytase, 4) NP1000: basal + 1,000 FTU/kg of phytase, and 5) NP2000: basal + 2,000 FTU/kg of phytase.

[3] Because scan weight on both a weight and an age basis was significantly different with phytase supplementation, scan weight was used as a covariate.

Appendix 4. Carcass characteristics for pigs fed high by-products diets with only xylanase supplementation (using scan weight as a covariate; Exp. 2)[1]

Treatment[2]:	PC	NC	NX	SEM	P-values
Phytase, FTU/kg:	0	0	0		
Item Xylanase, BXU/kg:	0	0	24,000		
Common weight basis					
Scan weight[3], kg	120.21	120.21	120.21	0.00	
Backfat, mm	**14.06**^{b}	**15.20**^{b}	**17.74**^{a}	0.69	**0.01**
Longissimus muscle depth, mm	57.76	63.74	65.30	3.79	0.45
Longissimus area, %	38.75	42.34	43.27	2.27	0.45
Carcass lean, %	56.84	56.87	55.52	0.69	0.24
Initial lean, kg	9.40	9.26	9.34	0.14	0.86
Final lean, kg	46.16	47.19	46.80	0.94	0.83
Lean gain, g/d	342.36	350.63	344.12	7.64	0.77
Lean gain/feed	0.141	0.142	0.135	0.006	0.56
Common age basis					
Scan weight[3], kg	118.03	118.03	118.03	0.00	
Backfat, mm	**14.20**^{b}	**14.84**^{b}	**17.16**^{a}	0.73	**0.03**
Longissimus muscle depth, mm	62.77	57.54	60.09	3.44	0.71
Longissimus area, %	41.76	38.62	40.15	2.06	0.71
Carcass lean, %	57.35	56.35	55.26	0.80	0.23
Initial lean, kg	9.35	9.30	9.36	0.15	0.96
Final lean, kg	46.63	45.24	45.14	0.97	0.61
Lean gain, g/d	355.01	342.32	340.81	9.45	0.62
Lean gain/feed	0.149	0.138	0.134	0.007	0.39

[a,b] Means within the same row without a common superscript differ ($P < 0.05$).

[1] Least squares means.

[2] Treatments were 1) PC: basal diet + fat, 2) NC: basal diet, and 3) NX: basal + 24,000 BXU/kg of xylanase.

[3] . Because scan weight on both a weight and an age basis was significantly different with phytase supplementation, scan weight was used as a covariate.

Appendix 5. Apparent total tract digestibility (%) for pigs fed high by-products diets with only phytase supplementation in Phase 4 (Exp. 2)^{1}

	Treatment^{2}:	PC	NC	NP500	NP1000	NP2000		
	Phytase, FTU/kg:	0	0	500	1,000	2,000	SEM	P-values
Item	Xylanase, BXU/kg:	0	0	0	0	0		
Dry matter		**76.84^{c}**	**77.74^{bc}**	**79.38^{a}**	**78.60^{ab}**	**78.59^{ab}**	**0.43**	**0.01**
Energy		**76.84^{f}**	**77.38^{ef}**	**78.98^{d}**	**77.68^{ef}**	**78.00^{de}**	0.46	**0.05**
Nitrogen		74.12	75.24	77.19	76.63	75.92	0.83	0.13
Ether extract		**76.64^{a}**	**66.21^{c}**	**74.58^{ab}**	**75.90^{ab}**	**69.74^{bc}**	2.28	**0.02**
Acid detergent fiber		50.07	49.52	53.53	53.40	51.28	**1.53**	0.26
Neutral detergent fiber		**49.33^{b}**	**50.38^{b}**	**55.56^{a}**	**52.40^{ab}**	**54.12^{a}**	**1.17**	**0.01**
Hemicellulose		**48.80^{f}**	**50.99^{ef}**	**57.03^{d}**	**51.68^{ef}**	**56.15^{de}**	**2.14**	**0.07**
Calcium		44.25	46.75	45.17	47.28	43.37	2.48	0.78
Phosphorus		**35.52^{c}**	**42.66^{b}**	**45.20^{b}**	**53.41^{a}**	**50.08^{a}**	**1.24**	**<.0001**

$^{a-c}$Means within the same row without a common superscript differ ($P < 0.05$).

$^{d-f}$Means within the same row without a common superscript differ ($P < 0.10$).

[1] Least squares means.

[2] Treatments were 1) PC: basal diet + fat, 2) NC: basal diet, 3) NP500: basal + 500 FTU/kg of phytase, 4) NP1000: basal + 1,000 FTU/kg of phytase, and 5) NP2000: basal + 2,000 FTU/kg of phytase.

Appendix 6. Apparent total tract digestibility (%) for pigs fed high by-products diets with only xylanase supplementation in Phase 4 (Exp. 2)^{1}

	Treatment^{2}:	PC	NC	NX		
	Phytase, FTU/kg:	0	0	0	SEM	P-values
Item	Xylanase, BXU/kg:	0	0	24,000		
Dry matter		76.84	77.74	77.41	0.32	0.21
Energy		76.84	77.38	76.83	0.42	0.60
Nitrogen		74.12	75.24	74.86	0.83	0.64
Ether extract		**76.64^{a}**	**66.21^{b}**	**63.80^{b}**	2.14	**0.01**
Acid detergent fiber		50.07	49.52	50.10	1.86	0.97
Neutral detergent fiber		49.33	50.38	50.32	1.14	0.77
Hemicellulose		48.80	50.99	50.48	2.05	0.74
Calcium		44.25	46.75	46.92	2.29	0.67
Phosphorus		**35.52^{b}**	**42.66^{a}**	**40.40^{a}**	1.31	**0.01**

^{a,b}Means within the same row without a common superscript differ ($P < 0.05$).

[1] Least squares means.

[2] Treatments were 1) PC: basal diet + fat, 2) NC: basal diet, and 3) NX: basal + 24,000 BXU/kg of xylanase.