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# Effects of microbial xylanase on digestibility of dry matter, organic matter, neutral detergent fiber, and energy and the concentrations of digestible and metabolizable energy in rice coproducts fed to weanling pigs[1]

**G. A. Casas*† and H. H. Stein*[2]**

*Department of Animal Sciences, University of Illinois, Urbana 61801; and †Departamento de Producción Animal, Facultad de Medicina Veterinaria y de Zootecnia, Universidad Nacional de Colombia, Bogotá, Colombia

**ABSTRACT:** The objective of this experiment was to test the hypothesis that the apparent total tract digestibility (ATTD) of DM, OM, fiber, and GE by weanling pigs and the concentration of DE and ME in full-fat rice bran (FFRB), defatted rice bran (DFRB), brown rice, and broken rice is improved if microbial xylanase is added to the diet. Eighty pigs (13.6 ± 0.8 kg initial BW) were allotted to 10 diets with 8 replicate pigs per diet in a randomized complete block design with 2 blocks of 40 pigs. A basal diet based on corn and soybean meal and 4 diets containing corn, soybean meal, and each of the 4 rice coproducts were formulated. The rice coproducts and corn and soybean meal were the only sources of energy in the diets. Five additional diets that were similar to the initial 5 diets with the exception that they also contained 16,000 units of xylanase (Econase XT-25; AB Vista, Marlborough, UK) were also formulated. All diets also contained 1,500 units of microbial phytase (Quantum Blue 5G; AB Vista). The DE and ME and the ATTD of DM, OM, fiber, and GE in diets and ingredients were calculated using the direct method and the difference method, respectively. Results indicated that the concentrations of DE and ME (DM basis) in FFRB and DFRB increased ($P < 0.05$) if xylanase was used. Broken rice had a greater ($P < 0.05$) concentration of DE and ME than FFRB and DFRB if no xylanase was added to the diets, but if xylanase was used, no differences in ME among FFRB, brown rice, and broken rice were observed. The ATTD of DM was greater ($P < 0.05$) in ingredients with xylanase than in ingredients without xylanase and there was a tendency ($P = 0.067$) for the ATTD of OM to be greater if xylanase was used. The ATTD of NDF in FFRB was greater ($P < 0.05$) when xylanase was added than if no xylanase was used, whereas the ATTD of NDF in DFRB was not affected by the addition of xylanase. In conclusion, if no xylanase was used, broken rice and brown rice have greater concentrations of DE and ME than FFRB and DFRB, and these values were not increased by microbial xylanase. However, xylanase increased the concentration of DE and ME (DM basis) in FFRB and DFRB.

**Key words:** digestibility, energy, pigs, rice bran, rice coproducts, xylanase

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## INTRODUCTION

Coproducts from the rice milling industry include rice hulls, rice bran, rice mill feed, brown rice, and broken rice (Singh et al., 2013). Rice hulls constitute about 20% of the weight of paddy rice but contain large quantities of lignin and silica and, therefore, are not used as a food or feed ingredient (Serna-Saldívar, 2010). Brown rice is the whole rice grain that is left after the hull layer has been removed, leaving the germ and bran layers. Rice bran is the outer brown layer of brown rice and includes several sublayers within the pericarp and aleurone layers. Those layers are removed to produce polished white rice for human consumption and results in production of rice bran, which contains 14 to 25% ether extract. Rice bran may be defatted, which reduces the concentration of ether extract to less than 5%. Broken rice is made up of fragments of grain that are generated

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[2]Corresponding author: hstein@illinois.edu

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**Table 1.** Analyzed nutrient composition of corn, soybean meal, brown rice, broken rice, full-fat rice bran (FFRB), and defatted rice bran (DFRB)

| | Ingredient | | | | | |
|---|---|---|---|---|---|---|
| Item | Corn | Soybean meal | Brown rice | Broken rice | FFRB | DFRB |
| GE, kcal/kg | 3,848 | 4,071 | 3,841 | 4,399 | 5,044 | 4,348 |
| DM, % | 83.3 | 88.5 | 88.1 | 88.1 | 96.2 | 91.0 |
| CP, % | 6.64 | 50.3 | 9.51 | 7.67 | 15.3 | 17.1 |
| AEE,[1] % | 2.02 | 1.09 | 3.15 | 1.42 | 19.28 | 1.11 |
| Ash, % | 0.83 | 5.56 | 1.22 | 1.25 | 8.04 | 11.97 |
| Starch, % | 69.1 | – | 66.8 | 76.8 | 29.6 | 28.3 |
| ADF, % | 3.11 | 4.99 | 1.37 | 0.46 | 9.09 | 12.0 |
| NDF, % | 8.56 | 6.80 | 2.66 | 0.61 | 14.13 | 19.27 |
| Lignin, % | 0.69 | 0.39 | 0.65 | 0.38 | 3.01 | 4.34 |
| Ca, % | 0.01 | 0.30 | 0.01 | 0.01 | 0.04 | 0.11 |
| P, % | 0.20 | 0.57 | 0.27 | 0.11 | 1.79 | 2.58 |
| Phytate, % | 0.49 | 1.31 | 0.79 | 0.22 | 5.82 | 8.43 |
| Phytate-bound P,[2] % | 0.13 | 0.37 | 0.22 | 0.06 | 1.62 | 2.36 |
| Phytate-bound P, % of total P | 65.0 | 64.9 | 81.5 | 54.5 | 90.5 | 91.5 |
| Nonphytate P,[3] % | 0.07 | 0.20 | 0.05 | 0.05 | 0.17 | 0.22 |
| Nonphytate-bound P, % of total P | 35.0 | 35.1 | 18.5 | 45.4 | 9.5 | 8.5 |

[1]AEE = acid-hydrolyzed ether extract.

[2]Phytate-bound P was calculated as 28.2% of phytate (Tran and Sauvant, 2004).

[3]Nonphytate P was calculated as the difference between total P and phytate-bound P.

during milling of rice and is used for brewing or other fermented products, for production of rice meal, or for animal feeding (Casas and Stein, 2015).

The concentration of nonstarch polysaccharides (**NSP**) in defatted rice bran (**DFRB**) is 20 to 25% and mainly consists of arabinoxylan and cellulose (Choct, 1997). The high concentration of NSP in rice bran has negative effects on the utilization of nutrients by pigs and may restrict the inclusion rate in diets for pigs. Addition of microbial xylanase to wheat coproducts, which also have high concentrations of NSP, may improve the digestibility of energy (Nortey et al., 2007; Zijlstra et al., 2010), but there is limited information about effects of adding microbial xylanases to rice coproducts. Therefore, the objective of this experiment was to test the hypothesis that the apparent total tract digestibility (**ATTD**) of DM, OM, fiber, and GE by starter pigs and the concentration of DE and ME in full-fat rice bran (**FFRB**), DFRB, brown rice, and broken rice is improved if microbial xylanase is added to the diet.

## MATERIALS AND METHODS

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois. Four rice coproducts were evaluated: FFRB, DFRB, brown rice, and broken rice (Table 1). Brown rice and broken rice were sourced from Augason Farms, Salt Lake City, UT, and Consumers Supply Distributing Co., North Sioux City, SD, respectively. Defatted rice bran and FFRB were sourced from RiceBran Technologies, Scottsdale, AR, and Triple Crown Nutrition Inc., Wayzata, MN, respectively.

### *Animals and Housing*

Eighty castrated male pigs that were the offspring of F-25 females mated to G-Performer males (Genetiporc USA LLC, Alexandria, MN) with an average initial BW of 13.6 ± 0.8 kg were randomly allotted to 10 diets with 8 replicate pigs per diet in a randomized complete block design with 2 blocks of 40 pigs. Pigs were individually housed in metabolism crates that were equipped with a feeder and a nipple drinker, a fully slatted floor, a screen floor, and a urine tray, which allowed for the total collection of feces and urine.

### *Diets and Feeding*

A basal diet based on corn and soybean meal and 4 diets containing corn, soybean meal, and 1 of the 4 rice coproducts were formulated (Table 2). Each rice coproduct was included at 50% in the diets and the ratio between corn and soybean meal remained constant in all diets. The rice coproducts and corn and soybean meal were the only sources of energy in the diets. Five additional diets that were similar to the initial 5 diets with the exception that they also contained 16,000 units of microbial xylanase (Econase XT-25; AB Vista, Marlborough, UK) were also formulated. All diets also contained 1,500

units of microbial phytase (Quantum Blue 5G; AB Vista), and vitamins and minerals were included in concentrations that exceeded the requirements for 11- to 25-kg pigs (NRC, 2012). Feed was provided at a daily level of 3 times the maintenance energy requirement (197 kcal/kg $BW^{0.60}$; NRC, 2012), and pigs were fed equal amounts of feed twice daily at 0800 and 1700 h. Water was available at all times throughout the experiment.

### *Sample Collection*

Pigs were fed experimental diets for 14 d. The initial 7 d were considered an adaptation period to the diet. Fecal markers (0.5%) were included in the morning meals on d 8 (chromic oxide) and d 13 (ferric oxide) and fecal collection was initiated when chromic oxide appeared in the feces and ceased when ferric oxide appeared (Kong and Adeola, 2014). Feces were collected twice daily and stored at −20°C as soon as collected. Urine collection started on d 8 at 1700 h and ceased on d 13 at 1700 h. Urine was collected in buckets placed under the metabolism crates that contained a preservative of 50 mL of 6 *N* HCL. Buckets were emptied daily, weights of the collected urine were recorded, and 20% of the collected urine was stored a −20°C. At the conclusion of the experiment, urines samples were thawed and mixed within animal and diet and subsamples were collected for energy analysis.

### *Chemical Analyses*

Fecal samples were dried at 65°C in a forced-air oven and ground through a 1-mm screen and urine samples were lyophilized before energy analysis as described by Kim et al. (2009). Samples of ingredients, diets, feces, and urine were analyzed for GE using an isoperibol bomb calorimeter (model 6300; Parr Instrument Company, Moline, IL). Benzoic acid was used as the standard for calibration. Samples of ingredients, diets, and feces were analyzed for DM (method 930.15; AOAC, 2007) and ash (method 942.05; AOAC, 2007) and ingredients and diets were analyzed for CP by combustion (method 990.03; AOAC, 2007) using an Elementar Rapid N-cube Protein/Nitrogen Apparatus (Elementar Americas Inc., Mt. Laurel, NJ). Ingredients were also analyzed for acid-hydrolyzed ether extract (**AEE**) by acid hydrolysis using 3 *N* HCl (Sanderson, 1986) followed by crude fat extraction using petroleum ether (method 2003.6; AOAC, 2007) on an automated analyzer (Soxtec 2050; FOSS North America, Eden Prairie, MN). Concentrations of ADF and NDF were determined in ingredients, diets, and feces using Ankom Technology method 12 and 13, respectively (Ankom 2000 Fiber Analyzer; Ankom Technology, Macedon, NY). Starch was analyzed in corn and all rice coproducts (method 979.10; AOAC, 2007)

**Table 2.** Composition of experimental diets containing brown rice, broken rice, full-fat rice bran (FFRB), or defatted rice bran (DFRB) without or with microbial xylanase

| | Diet[1] | | | | |
|---|---|---|---|---|---|
| Ingredient, % | Basal | Brown rice | Broken rice | FFRB | DFRB |
| Corn | 57.50 | 27.35 | 27.35 | 27.50 | 27.50 |
| Soybean meal | 39.00 | 18.9 | 18.90 | 19.00 | 19.00 |
| Rice coproducts | – | 50.00 | 50.00 | 50.00 | 50.00 |
| Limestone | 1.30 | 1.05 | 0.90 | 1.80 | 1.80 |
| Dicalcium phosphate | 0.50 | 1.00 | 1.15 | – | – |
| Sodium chloride | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Vitamin–mineral premix[2] | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Phytase–xylanase premix[3] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Analyzed composition | | | | | |
| Diets without xylanase | | | | | |
| GE, kcal/kg | 3,797 | 3,755 | 3,746 | 4,355 | 3,724 |
| DM, % | 86.93 | 87.90 | 87.92 | 91.78 | 88.99 |
| CP, % | 21.70 | 15.50 | 15.15 | 18.80 | 19.70 |
| Ash, % | 5.29 | 4.74 | 3.96 | 7.48 | 9.15 |
| NDF, % | 6.91 | 5.45 | 5.13 | 9.16 | 14.25 |
| ADF, % | 3.47 | 2.73 | 2.35 | 5.14 | 6.67 |
| Ca, % | 0.92 | 0.56 | 0.69 | 0.89 | 0.88 |
| P, % | 0.46 | 0.51 | 0.43 | 1.04 | 1.42 |
| Xylanase, units/kg | ND[4] | ND | ND | ND | ND |
| Phytase, units/kg | 1,660 | 1,800 | 1,870 | 1,920 | 2,020 |
| Diets with xylanase | | | | | |
| GE, kcal/kg | 3,820 | 3,777 | 3,717 | 4,412 | 3,716 |
| DM, % | 87.09 | 87.35 | 88.26 | 91.82 | 89.10 |
| CP, % | 23.4 | 15.0 | 14.0 | 18.4 | 19.7 |
| Ash, % | 5.15 | 4.31 | 4.08 | 7.19 | 9.38 |
| NDF, % | 7.20 | 5.67 | 4.45 | 10.36 | 13.29 |
| ADF, % | 3.47 | 2.53 | 2.79 | 5.65 | 6.61 |
| Ca, % | 0.64 | 0.57 | 0.72 | 0.79 | 0.86 |
| P, % | 0.44 | 0.50 | 0.44 | 1.11 | 1.41 |
| Xylanase, units/kg | 18,700 | 21,100 | 20,900 | 21,900 | 23,400 |
| Phytase, units/kg | 1,520 | 1,480 | 1,620 | 1,880 | 1,650 |

[1]Five diets were formulated without xylanase and 5 diets were formulated with xylanase.

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

[3]The phytase–xylanase premix contained either phytase (Quantum Blue; 5,000 units per gram; AB Vista, Marlborough, UK) or phytase and xylanase (Econase XT-25; 160,000 units per gram; AB Vista) mixed with corn. The mixture was formulated to provide 1,500 units of phytase per kilogram of complete feed in all diets and 16,000 units of xylanase per kilogram of complete feed in all xylanase-containing diets.

[4]ND = not detected.

**Table 3.** Intake and output of energy, apparent total tract digestibility (ATTD) of energy, and concentrations of DE and ME by weanling pigs fed a basal corn–soybean meal–based diet or diets containing brown rice, broken rice, full-fat rice bran (FFRB), or defatted rice bran (DFRB) without or with microbial xylanase[1,2,3]

| Item | GE intake, kcal/d | GE in feces, kcal/d | GE in urine, kcal/d | ATTD of GE, % | DE, kcal/kg | ME, kcal/kg | ATTD of DM, % | ATTD of OM, % | ATTD of NDF, % | ATTD of ADF, % |
|---|---|---|---|---|---|---|---|---|---|---|
| Without xylanase | | | | | | | | | | |
| Basal diet | 3,485 | 413$^{c}$ | 139 | 86.9 | 3,301$^{d}$ | 3,144 | 88.9 | 89.6 | 62.8$^{b}$ | 66.7 |
| Brown rice | 3,343 | 288$^{d}$ | 92 | 90.9 | 3,413$^{c}$ | 3,308 | 92.3 | 93.0 | 69.2$^{a}$ | 68.0 |
| Broken rice | 3,774 | 277$^{d}$ | 97 | 91.9 | 3,439$^{bc}$ | 3,337 | 92.6 | 93.3 | 73.2$^{a}$ | 71.8 |
| FFRB | 3,668 | 700$^{b}$ | 114 | 80.8 | 3,520$^{b}$ | 3,383 | 81.9 | 82.9 | 44.5$^{d}$ | 42.7 |
| DFRB | 4,157 | 874$^{a}$ | 109 | 79.5 | 2,960$^{f}$ | 2,914 | 79.5 | 82.4 | 59.0b$^{c}$ | 50.4 |
| With xylanase | | | | | | | | | | |
| Basal diet | 4,504 | 456$^{c}$ | 122 | 86.6 | 3,308$^{d}$ | 3,175 | 88.9 | 89.1 | 59.6$^{bc}$ | 63.3 |
| Brown rice | 3,431 | 323$^{d}$ | 90 | 90.5 | 3,419$^{c}$ | 3,320 | 91.8 | 92.7 | 70.5$^{a}$ | 65.9 |
| Broken rice | 3,480 | 286$^{d}$ | 96 | 91.5 | 3,401$^{c}$ | 3,297 | 91.8 | 93.4 | 70.7$^{a}$ | 75.8 |
| FFRB | 4,053 | 721$^{b}$ | 108 | 82.4 | 3,637$^{a}$ | 3,509 | 82.4 | 83.6 | 56.7$^{c}$ | 46.1 |
| DFRB | 4,276 | 726$^{b}$ | 107 | 82.5 | 3,103$^{e}$ | 3,011 | 80.8 | 84.3 | 60.3$^{bc}$ | 49.8 |
| SEM | 142.13 | 33.91 | 9.79 | 1.03 | 36.48 | 43.38 | 0.56 | 0.617 | 2.08 | 2.36 |
| *P*-value | | | | | | | | | | |
| Diet | <0.001 | <0.001 | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Xylanase | 0.121 | 0.644 | 0.352 | 0.224 | 0.029 | 0.074 | 0.228 | 0.294 | 0.152 | 0.847 |
| Diet × xylanase | 0.484 | 0.011 | 0.923 | 0.227 | 0.038 | 0.243 | 0.284 | 0.245 | 0.001 | 0.272 |

$^{a–e}$Means within a column lacking a common superscript letter are different ($P < 0.05$).

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

[2]Microbial phytase (Quantum blue 5G; AB Vista, Marlborough, UK; 5,000 units per gram) was included in all diets to provide 1,500 units of phytase per kilogram of complete feed.

[3]Xylanase (Econase XT-25; AB Vista; 160,000 units per gram) was include in the xylanase containing diets to provide 16,000 units of xylanase per kilogram of complete feed.

and all ingredients were analyzed for phytate (Ellis et al., 1977) and lignin (Ankom Technology method 9). Calcium and P were analyzed in all ingredients and diets (method 985.01; AOAC, 2007). Xylanase activity (ELISA method; AB Vista) and phytase activity (Engelen et al., 2001) were also analyzed in all diets.

### *Calculations and Statistical Analysis*

Organic matter was calculated as the difference between DM and ash. Phytate-bound P was calculated as 28.2% of phytate (Tran and Sauvant, 2004). Nonphytate P was calculated as the difference between total P and phytate-bound P. The DE and ME and the ATTD of GE, DM, OM, ADF, and NDF in all diets were calculated using the direct procedure (Kong and Adeola, 2014). The contribution of DE and ME from the basal diet to the diets containing rice coproducts was subtracted from the DE and ME that were calculated for these diets and the DE and ME in each rice coproduct was then calculated by the difference (Adeola, 2001). A similar approach was used to calculate the ATTD of GE, DM, OM, ADF, and NDF. Outliers and homogeneity of the variances among treatments was tested using the UNIVARIATE procedure. Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) as a 5 × 2 factorial for diets and a 4 × 2 factorial for ingredients. The fixed effects were the diet or ingredient, xylanase, and the interaction between diet or ingredient and xylanase. Block and replicate were considered random effects. Diet or ingredient and xylanase were the main effects. The least squares mean statement was used to calculate treatment means, and the PDIFF option was used to separate means if differences were detected. The pig was the experimental unit for all analyses. An α level of 0.05 was used to assess significance among dietary treatments, and if the *P*-value was >0.05 but <0.10, the difference was considered a trend.

## RESULTS

The concentration of GE was 4,399, 3,841, 5,044, and 4,348 kcal/kg in broken rice, brown rice, FFRB, and DFRB, respectively (Table 1). The concentration of AEE was 1.42, 3.15, 19.28, and 1.11% in broken rice, brown rice, FFRB, and DFRB, respectively, whereas the concentration of starch was 76.8% in broken rice, 66.8% in brown rice, 29.6% in FFRB, and 28.3% in DFRB. The concentrations of NDF and ADF were 0.61 and 0.46%, respectively, in broken rice, 2.66 and 1.37%, respectively,

**Table 4.** Concentration of DE and ME, and apparent total tract digestibility (ATTD) of energy by weanling pigs in brown rice, broken rice, full-fat rice bran (FFRB), and defatted rice bran (DFRB) without or with xylanase[1,2,3]

| Item | ATTD of GE, % | DE, kcal/kg of DM | ME, kcal/kg of DM | ATTD of DM, % | ATTD of OM, % | ATTD of NDF, % | ATTD of ADF, % |
|---|---|---|---|---|---|---|---|
| Without xylanase | | | | | | | |
| Brown rice | 94.8 | 4,120$^{bc}$ | 4,055$^{ab}$ | 94.6 | 96.2 | 75.4$^{b}$ | 68.8 |
| Broken rice | 96.4 | 4,183$^{ab}$ | 4,124$^{a}$ | 95.3 | 96.0 | 86.4$^{a}$ | 74.4 |
| FFRB | 75.6 | 3,984$^{c}$ | 3,856$^{b}$ | 72.8 | 73.7 | 30.8$^{d}$ | 27.3 |
| DFRB | 76.7 | 3,054$^{d}$ | 2,936$^{d}$ | 72.9 | 77.0 | 54.9$^{c}$ | 47.2 |
| With xylanase | | | | | | | |
| Brown rice | 94.4 | 4,127$^{ab}$ | 4,047$^{ab}$ | 94.9 | 96.5 | 77.6$^{b}$ | 62.2 |
| Broken rice | 96.0 | 4,087$^{bc}$ | 3,995$^{ab}$ | 96.7 | 97.3 | 86.4$^{a}$ | 89.5 |
| FFRB | 80.8 | 4,311$^{a}$ | 4,198$^{a}$ | 75.8 | 77.2 | 55.3$^{c}$ | 39.9 |
| DFRB | 79.0 | 3,192$^{d}$ | 3,225$^{c}$ | 74.3 | 77.2 | 56.8$^{c}$ | 48.8 |
| SEM | 2.21 | 70.84 | 81.87 | 1.32 | 1.44 | 3.09 | 5.37 |
| *P*-value | | | | | | | |
| Ingredient | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Xylanase | 0.176 | 0.038 | 0.0321 | 0.043 | 0.067 | 0.001 | 0.109 |
| Ingredient × xylanase | 0.304 | 0.007 | 0.010 | 0.628 | 0.303 | <0.001 | 0.125 |

$^{a–d}$Means within a column lacking a common superscript letter are different ($P < 0.05$).

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

[2]Microbial phytase (Quantum blue 5G; AB Vista, Marlborough, UK; 5,000 units per gram) was included in all diets to provide 1,500 units of phytase per kilogram of complete feed.

[3]Xylanase (Econase XT-25; AB Vista; 160,000 units per gram) was include in the xylanase containing diets to provide 16,000 units of xylanase per kilogram of complete feed.

in brown rice, 14.13 and 9.09%, respectively, in FFRB, and 19.27 and 12.0%, respectively, in DFRB.

The concentration of CP, Ca, P, NDF, and ADF in all diets was in agreement with expected values. The concentration of xylanase in all diets without added xylanase was not detectable, and in diets with added xylanase, the analyzed concentration ranged between 18,700 and 23,400 units/kg (Table 2). All diets contained more than 1,480 units/kg of phytase.

Fecal excretion of GE was reduced ($P < 0.05$) in pigs fed diets containing DFRB with xylanase compared with pigs fed DFRB without xylanase (Table 3), but for all other diets, no effect of xylanase on GE excretion was observed (interaction, $P < 0.05$). The DE of diets containing FFRB and DFRB increased ($P < 0.05$) if xylanase was added, but that was not the case for the basal diet and the diets containing brown rice or broken rice (interaction, $P < 0.05$). The ATTD of GE, DM, OM, and ADF and the ME of diets containing rice coproducts were not affected by addition of xylanase. However, the ATTD of NDF in pigs fed diets containing FFRB was greater ($P < 0.05$) when xylanase was added than if no xylanase was included in the diets, but that was not the case for the other diets (interaction, $P < 0.05$).

The ATTD of DM was greater ($P < 0.05$) in ingredients with xylanase than in ingredients without xylanase and there was a tendency ($P = 0.067$) for the ATTD of OM to be greater if xylanase was used (Table 4). If xylanase was added, the ATTD of NDF in FFRB was greater ($P < 0.05$) than if no xylanase was used, whereas the ATTD of NDF in DFRB was not affected by the addition of xylanase. The ATTD of ADF was not affected by addition of xylanase. The concentration of DE (as-is basis) and the concentration of ME (DM basis) in DFRB were greater ($P < 0.05$) if xylanase was used than if no xylanase was added, and DE and ME were greater in FFRB with xylanase (as-is and DM basis) than in FFRB without xylanase, but xylanase did not affect the concentration of DE or ME in brown rice or broken rice (interaction, $P < 0.05$). The DE and ME of FFRB, brown rice, and broken rice were greater ($P < 0.05$) than the ME of DFRB regardless of the level of xylanase in the diet, and DE and ME in broken rice without xylanase were greater ($P < 0.05$) than in FFRB. However, if xylanase was used, no differences in ME among FFRB, brown rice, and broken rice were observed, but the DE was greater ($P < 0.05$) in FFRB than in broken rice.

## DISCUSSION

Rice is primarily used for human consumption, but several coproducts are generated during the milling process and these coproducts may be used for animal feeding. The physical and chemical composition of rice coproducts depends on rice variety, treatment of the grain before milling, type of milling system,

degree of milling, and the fractionation processes used during milling (Saunders, 1985).

The concentrations of GE, AEE, ADF, starch, CP, Ca, and P in corn and soybean meal were within the range of values previously reported (NRC, 2012). The nutrient composition of the broken rice and brown rice used in this experiment was also in agreement with previous values, except for the concentration of ADF and NDF, which were less than reported values (Robles and Ewan, 1982; Warren and Farrell, 1990; Li et al., 2002; Sauvant et al., 2004; NRC, 2012; Cervantes-Pahm et al., 2014). The content of GE, CP, ash, starch, ADF, Ca, and P in FFRB and DFRB concurred with reported values (Robles and Ewan, 1982; Sauvant et al., 2004; Kaufmann et al., 2005; NRC, 2012). However, values for NDF in FFRB and DFRB and the concentration of AEE in DFRB were less than previous values (Maniñgat and Juliano, 1982; Robles and Ewan, 1982; Sauvant et al., 2004; Kaufmann et al., 2005; NRC, 2012), and the concentration of AEE in FFRB was greater than the values previously reported (Robles and Ewan, 1982; Sauvant et al., 2004; Kaufmann et al., 2005; NRC, 2012).

The DE and ME that were determined for the basal diet were close to values that can be calculated from the DE and ME in corn and soybean meal (NRC, 2012). In contrast, values for DE and ME in diets containing broken rice without and with xylanase were less than values previously reported (Robles and Ewan, 1982; Sauvant et al., 2004), but the DE and ME in diets containing FFRB without xylanase were in agreement with values reported by Robles and Ewan (1982). The observation that DE and ME in diets containing broken rice and brown rice were not affected by microbial xylanase whereas DE and ME of diets containing FFRB and DFRB increased when xylanase was added, likely as a result of the high concentration of starch and low concentration of NSP in diets containing broken rice and brown rice compared with diets containing FFRB and DFRB. Microbial xylanase mainly has activity on the xylan chain in arabinoxylan, which represents 29 to 46% of hemicellulose in FFRB and DFRB (Maniñgat and Juliano, 1982; Shibuya and Iwasaki, 1985; Annison et al., 1995; Paloheimo et al., 2010), whereas broken rice and brown rice contain less than 2% arabinoxylan (Choct, 1997).

The NSP in corn consist of almost 50% arabinoxylan (Jaworski et al., 2015), but because NSP contribute only around 8% of the DM in corn, the concentration of arabinoxylan in corn DM is only around 4%. Therefore, with 57.5% corn in the basal diet, the calculated concentration of arabinoxylan in the basal diet was less than 2.5%, which is likely the reason for the lack of a measurable effect of xylanase in the basal diet.

Values for DE and ME in broken rice and brown rice without xylanase concur with reported values (Li et al., 2002; Cervantes-Pahm et al., 2014), but DE and ME of FFRB and DFRB without xylanase were greater than previous values (Sauvant et al., 2004; NRC, 2012), which may be a result of differences in nutrient composition that are observed among sources of FFRB and DFRB.

The increase in DE and ME of FFRB and DFRB that was a result of xylanase addition is likely a result of hydrolysis of the xylan backbone in the arabinoxylan in FFRB and DFRB. This may reduce the viscosity of digesta and increase the release of starch attached to NSP and thereby increase the digestibility of energy (Kim et al., 2005; Paloheimo et al., 2010). The increase in DE and ME of FFRB concurs with the increase in the ATTD of NDF that was observed if xylanase was added to the diet. However, the increased DE in FFRB that was a result of xylanase addition may also be a result of greater digestibility of fat in diets supplemented with xylanase as a result of increased absorptive capacity in the small intestine and a reduction in the population of bacteria that are able to hydrolyze bile salts (Mathlouthi et al., 2002; Adeola and Cowieson, 2011). Although effects of xylanase were not evident in previous studies, nutrient digestibility depends on the composition of carbohydrates in the diet (Kim et al., 2008). The low arabinose-to-xylose ratio reported in DFRB and FFRB indicates that the arabinose substitution of the xylose backbone in arabinoxylan may have been less than in other cereal coproducts (Shibuya and Iwasaki, 1985). This may have increased the effects of the microbial xylanase because the oligosaccharides that are released after action of xylanase are more fermentable if the arabinose substitution is reduced (Bach Knudsen, 2014).

The observation that diets containing broken rice, brown rice, or FFRB contained more DE than the basal diet demonstrates that any of these coproducts may be added to diets fed to pigs without compromising the energy concentration in the diet. Specifically, the high DE and ME in the diet containing FFRB indicates that FFRB is a very good source of energy when fed to weanling pigs. In contrast, the DE in diets containing DFRB is less than in a corn–soybean meal diet even if xylanase is added to the diet, which indicates that DFRB may not be an ideal feed ingredient in diets fed to weanling pigs. However, all pigs in this experiment were fed restricted and there is, therefore, a need for conducting research with pigs that are allowed ad libitum access to feed to determine if feed intake and energy intake of pigs is influenced by FFRB or DFRB in the diet.

## *Conclusions*

Broken rice and brown rice have greater concentration of DE and ME than FFRB and DFRB, but these values were not affected by microbial xylanase. In contrast, microbial xylanase may increase the concentration of DE

and ME in FFRB and DFRB, because of greater concentration of arabinoxylan in those ingredients. There are no difference in ME among FFRB, broken rice, and brown rice if microbial xylanase is used, but DFRB contains less DE and ME than the other rice coproducts.

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