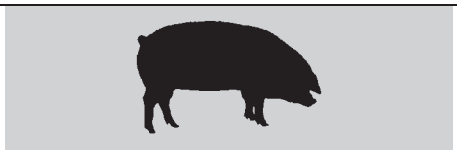
The Professional Animal Scientist 29 (2013):508–517



Evaluation of commercially available enzymes, probiotics, or yeast on apparent total-tract nutrient digestion and growth in nursery and finishing pigs fed diets containing corn dried distillers grains with solubles

B. J. Kerr,*[1] T. E. Weber,*[2] and G. C. Shurson†
*USDA-ARS National Laboratory for Agriculture and the Environment, Ames, IA 50011; and
†Department of Animal Science, University of Minnesota, St. Paul 55108

ABSTRACT

The ability of enzymes, direct-fed microbials, or yeast to enhance nutrient utilization or growth performance in nursery or finishing pigs fed diets containing increased levels of fiber from corn distillers dried grains with solubles is largely unknown. A total of 192 nursery (11.9 kg initial BW) and 96 finishing (98.4 kg initial BW) pigs were allotted to individual pens and fed their respective diets for 5 wk. Diets containing corn, soybean meal, and 30% corn distillers dried grains with solubles were adequate in all nutrients and were offered ad libitum in meal form. Additives were included at the recommended rates and were assumed to contain the active ingredients and activity level listed on the product label. In the starter experiment, Allzyme and Releezyme decreased GE, N, C, P, ADF, and NDF digestibility ($P < 0.05$), whereas Econase decreased S, P, and NDF digestibility ($P < 0.05$). In the finisher experiment, Allzyme increased P digestibility ($P < 0.05$), BactoCel decreased N digestibility ($P = 0.05$), BioPlus2B decreased ether extract digestibility ($P < 0.05$), Hemicel decreased ADF digestibility ($P < 0.05$), Porzyme decreased GE, N, C, S, P, ADF, and NDF digestibility ($P < 0.05$), Releezyme decreased GE, N, C, S, P, ADF, and ether extract digestibility ($P < 0.05$), and XPC yeast decreased GE and C digestibility ($P = 0.05$). No effect on nursery- or finishing-pig growth performance because of any feed additive was noted ($P > 0.10$). In conclusion, even though some of the feed additive products evaluated had small effects on nutrient digestibility, none of the products affected starter- and finishing-pig growth performance when fed nutritionally adequate corn-soy diets containing 30% corn distillers dried grains with solubles.

Key words: corn distillers dried grains with solubles, digestibility, feed additive, pig

INTRODUCTION

Pigs are capable of using moderate levels of fiber in the nursery (Whitney and Shurson, 2004; Weber et al., 2008) and finisher (Whitney et al., 2006) period, yet there is a need to increase digestion of structural carbohydrates, especially in corn-derived coproducts. Use of exogenous feed additives to improve the nutritional value of corn coproducts, particularly corn distillers dried grains with solubles (**C-DDGS**), which are relatively high in fiber (25% NDF, Stein

[1] Corresponding author: brian.kerr@ars.usda.gov
[2] Current address: Elanco, 2500 Innovation Way, Greenfield, IN 46140.

and Shurson, 2009), would be of great value to the swine industry.

The addition of exogenous feed additives to improve nutrient digestion is not a new concept, and responses have been reviewed elsewhere (Bedford, 2000; Adeola and Cowieson, 2011). The majority of commercial enzyme products have largely targeted poultry fed non-corn-based diets (Cowan, 1993; Hubener et al., 2002; Saleh et al., 2005). Likewise, the majority of research on enzymes in swine feeds has focused on non-corn-based diets (Yin et al., 2000; Moeser and van Kempen, 2002; Omogbenigun et al., 2004). Limited research results have been reported on the effect of exogenous enzymes on nutrient digestibility and growth performance of pigs fed corn-based diets (Pettey et al., 2002; Kim et al., 2003; Ji et al., 2008), with little information available on the use of enzyme preparations in diets containing C-DDGS (Spencer et al., 2007; Jacela et al., 2010; Yoon et al., 2010). Direct-fed microbials may modulate gastrointestinal bacterial populations (Apgar et al., 1993; Zeyner and Boldt, 2006; Davis et al., 2008), but no data relative to these products in C-DDGS containing diets were found. The effect of yeast and yeast products on nutrient metabolism is also variable (Kornegay et al., 1995; van Heugten et al., 2003; Spark et al., 2005), but again, no data relative to these products in C-DDGS containing diets were found.

Objectives of this study were to evaluate the ability of commercially available enzymes, direct-fed microbials, or a yeast preparation to improve growth performance and apparent total-tract digestibility of C, ether extract (**EE**), P, N, S, GE, ADF, and NDF in diets containing 30% C-DDGS fed to nursery or finisher pigs.

MATERIALS AND METHODS

Diets

The experiment was approved by the Iowa State University Animal Care and Use Committee, 12-07-6481-S. Feed additives (Table 1) were selected based on their claimed potential to affect energy and fiber digestion or ability to modulate the microbial ecology within the gastrointestinal tract. The basal diets (Table 2) were formulated to be adequate in energy and nutrients relative to the NRC (1998) recommendation over the 5-wk period. Diets included 30% C-DDGS during each phase of growth, which is representative of the common dietary inclusion level of C-DDGS used by the United States swine industry at the time this study was conducted. Feed additives were added into the complete feeds using the manufacturers' recommended rates, and it was assumed that they contained the active ingredients and the level of activity listed on the product label (Table 1).

Experimental Design

In the nursery experiment, a total of 192 pigs were used, representing 3 groups of 64 pigs (11.9 kg average initial BW, SD = 1.9 kg). Within each group, pigs were randomly allotted into 2 rooms, with each room containing 32 individual stainless-steel pens measuring 0.46 × 1.22 m, resulting in 16 to 18 individually fed pigs (replications) per treatment. In the finisher experiment, a total of 88 pigs were used, representing 2 groups of 44 pigs (98.4 kg average initial BW, SD = 8.5 kg). Within each finisher group, pigs were randomly allotted to 2 rooms, with each room containing 22 individual galvanized steel pens measuring 0.57 × 2.21 m, resulting in 8 replications per treatment. In each experiment, pigs and feeders were weighed at the beginning and end of the experimental period to calculate ADG, ADFI, and G:F ratio.

In each experiment, pigs were individually fed their experimental diets over the 5-wk feeding period and allowed ad libitum access to feed and water. Each room was maintained with 24-h lighting, was mechanically ventilated, and had a pull-plug manure storage system. Experimental diets were fed in meal form, with dietary treatments randomly assigned to pig within pen. Fecal samples were collected at the end of wk 1, 3, and 5 by collecting a grab sample of freshly voided feces into individual plastic bags and immediately storing samples at 0°C until the end of the trial.

Analytical Methods

At the end of the trial, diets and feces were dried in a 70°C forced-air oven, weighed, and ground through a 1-mm screen, and a subsample was obtained for nutrient analysis. Diet and fecal samples were analyzed in duplicate. Carbon, N, and S were analyzed using thermocombustion (VarioMax, Elementar Analysensysteme GmbH, Hanau, Germany). Acid and neutral detergent fibers were analyzed using filter-bag technology (Ankom2000, method #8-ADF, method #9-NDF, Ankom Technology, Macedon, NY). Ether extract was analyzed using petroleum ether as described by Luthria et al. (2004) using an ASE 350 (Dionex Corporation, Sunnyvale, CA). Gross energy was determined using an isoperibol bomb calorimeter (Model 1281, Parr Instrument Co., Moline, IL), with benzoic acid used as a standard. Phosphorus was digested with concentrated nitric acid following method (II)A (AMC, 1960) in 1 *N* HCl followed by inductively coupled plasma spectrometry (Optima 5300DV, PerkinElmer, Shelton, CT). Titanium dioxide was analyzed in the feed and feces by digesting the samples in sulfuric acid and hydrogen peroxide, and subsequent absorbance was measured using a UV spectrophotometer (Method 988.05; AOAC, 1978).

Calculations and Statistical Methods

Titanium dioxide (TiO_2) was added as an indigestible marker at 0.5% of the diet to determine apparent total-tract nutrient digestibility by the indirect method: $\{1 - [(Ti_{feed} \times Nutrient_{feces})/(Ti_{feces} \times Nutrient_{feed})]\}$. The experiment was designed as a randomized block design with group, room, sex, and week considered as

Table 1. Characteristics of exogenous feed additives

Trade name	Activity identification	Stated activity[1]	Inclusion, rate S[2]	Inclusion, rate F[2]
Allzyme SSF[3]	*Aspergillus niger* (phytase)	300 FTU/g	500	500
BactoCell[4]	*Pediococcus acidilactici*	10 × 10^9 cfu/g	110	110
BioPlus 2B[5]	*Bacillus licheniformis* and *subtilis*	2.2 × 10^9 cfu/g	500	500
Econase XT25[6]	Endo-1,4-β-xylanase	160,000 U/g	150	150
Hemicel[7]	Hemicellulase	1.4 × 10^6 U/g	500	500
Porzyme 9302[8]	Xylanase	8,000 U/g	250	250
Releezyme 4M[9]	β-Glucanase	440 U/g	500	500
	Protease	11 U/g		
Rovabio AP10[10]	Endo-1,4-β-xylanase	2,200 U/g	500	500
	Endo-1,3(4)-β-glucanase	200 U/g		
Roxazyme G2G[11]	Endo-1,4-β-glucanase	8,000 U/g	220	220
	Endo-1,3(4)-β-glucanase	18,000 U/g		
	Endo-1,4-β-xylanase	26,000 U/g		
XPC yeast[12]	*Saccharomyces cerevisiae* yeast culture	NA	2,000	1,000

[1]Activity as reported by the supplier. FTU = phytase units, U = units.

[2]Addition of additive (mg) per kilogram of feed during the starter (S) and finisher (F) experiment.

[3]Alltech, Lexington, Kentucky.

[4]Lallemand Animal Nutrition, Milwaukee, Wisconsin.

[5]Chr. Hansen, Milwaukee, Wisconsin.

[6]AB Enzymes, Darmstadt, Germany.

[7]ChemGen Corp., Gaithersburg, Maryland.

[8]Danisco Animal Nutrition, Marlborough, UK.

[9]Prince Agri Products Inc., Quincy, Illinois.

[10]Adisseo, Antony, France.

[11]DSM Nutritional Products Inc., Parsippany, New Jersey.

[12]Diamond V Mills Inc., Cedar Rapids, Iowa.

blocking effects. Because there were no week × diet interactions, only the main effects of diet and week are presented. In addition, only the preplanned comparisons between pigs fed each feed additive and pigs fed the diet containing no additive are presented. Data were subjected to ANOVA (Proc GLM, SAS Institute Inc., Cary, NC) with the pig considered the experimental unit in each experiment with treatment means reported as least squares means. Results are presented relative to $P \leq 0.10$ and $P \leq 0.05$.

RESULTS AND DISCUSSION

In the starter experiment, nutrient digestibility coefficients were affected by the addition of only a few of the feed additives evaluated (Table 3). Among the enzymes, Allzyme (Alltech, Lexington, KY) decreased GE, N, C, P, ADF, and NDF digestibility ($P \leq 0.01$), Econase (AB Enzymes, Darmstadt, Germany) decreased S, P, and NDF ($P < 0.05$) and tended to decrease GE, N, C, and ADF digestibility ($P \leq 0.10$), Hemicel (ChemGen Corp., Gaithersburg, MD) tended to decrease NDF digestibility ($P < 0.10$), Porzyme (Danisco Animal Nutrition, Marlborough, UK) tended to decrease NDF digestibility ($P < 0.10$), Releezyme (Prince Agri Products Inc., Quincy, IL) decreased GE, N, C, P, ADF, and NDF ($P \leq 0.01$) and tended to decrease S and EE digestibility ($P < 0.10$), Roxazyme (DSM Nutritional Products Inc., Parsippany, NJ) tended to increase N and S digestibility ($P \leq 0.10$), and Rovabio (Adisseo, Antony, France) tended to increase S digestibility ($P < 0.10$). Feeding XPC yeast (Diamond V Mills Inc., Cedar Rapids, IA) tended to decrease P digestibility ($P < 0.10$), whereas BactoCel (Lallemand Animal Nutrition, Milwaukee, WI) increased S digestibility ($P < 0.05$). Digestibility of GE, N, C, S, P, ADF, and NDF increased from wk 1 to 5 ($P \leq 0.01$), whereas digestibility of EE decreased from wk 1 to 5 ($P \leq 0.01$).

During the finisher experiment, little effect of enzymes, microbial cultures, or yeast were noted for most nutrient digestibility coefficients (Table 4). Among the enzyme products, Allzyme increased P ($P \leq 0.01$) and tended to increase ADF and NDF digestibility ($P < 0.10$), Hemicel decreased ADF ($P < 0.05$) and tended to decrease NDF digestibility ($P < 0.10$), Porzyme decreased GE,

Table 2. Composition (as-fed basis) of experimental diets

Item	Starter	Finisher
Ingredient, %		
Corn	41.69	61.98
Soybean meal	16.94	4.85
Dried distillers grains with solubles	30.00	30.00
Whey, dried	5.00	—
Fish meal	2.50	—
Soybean oil	0.52	—
Dicalcium phosphate	0.34	—
Limestone	0.96	1.11
Sodium chloride	0.35	0.35
Vitamin mix[1]	0.30	0.25
Trace mineral mix[2]	0.11	0.10
L-Lysine·HCl	0.27	0.33
L-Tryptophan	0.02	0.03
Dehulled, degermed corn	0.45	0.475
Antibiotic[3]	0.05	0.025
Titanium dioxide	0.50	0.50
Total	100.0	100.0
Analyzed composition		
GE, Mcal/kg	4.16	4.04
ADF, %	5.27	4.58
Carbon, %	41.33	40.70
CP, %	21.81	15.56
Ether extract, %	5.49	4.92
NDF, %	12.41	12.40
Phosphorus, %	0.68	0.44
Sulfur, %	0.36	0.32
Titanium dioxide, %	0.45	0.51

[1]Provided the following per kilogram of starter and finisher diet, respectively: vitamin A, 6,614 IU, 5,512 IU; vitamin D_3, 1,653 IU, 1,378 IU; vitamin E, 33 IU, 28 IU; vitamin B_{12}, 0.033 mg, 0.028 mg; riboflavin, 10 mg, 8 mg; niacin, 50 mg, 41 mg; pantothenic acid, 26 mg, 22 mg.

[2]Provided the following per kilogram of starter and finisher diet, respectively: Cu (oxide), 11 mg, 9 mg; Fe (sulfate), 105 mg, 88 mg; I (CaI), 1.2 mg, 1.0 mg; Mn (oxide) 36 mg, 30 mg; Zn (oxide), 90 mg, 75 mg; Se (Na_2SeO_3), 0.3 mg, 0.3 mg.

[3]Tylan 40 (Elanco Animal Health, Indianapolis, IN) provided 44 and 22 mg tylosin phosphase per kilogram of diet in the starter and finisher diet, respectively.

N, C, S, P, ADF, and NDF digestibility ($P \leq 0.01$), Releezyme decreased GE, N, C, S, P, NDF, and EE digestibility ($P < 0.05$), and Roxazyme tended to increase EE digestibility ($P < 0.10$). Dietary addition of XPC yeast decreased GE and C ($P \leq 0.05$) and tended to decrease N, P, and EE digestibility ($P \leq 0.10$); BactoCel decreased N digestibility ($P \leq 0.05$); and BioPlus2B (Chr. Hansen, Milwaukee, WI) decreased EE ($P \leq 0.01$) but tended to increase ADF digestibility ($P \leq 0.10$). Nutrient digestibility did not change from wk 1 to 5 for finishing pigs. There was no effect of enzymes, microbial cultures, or yeast on either starter or finisher growth performance (Table 5).

The current experiments largely focused on the ability of various feed additives to affect digestion and were mainly concerned with components associated with energy digestion. Thus, we initially focused on measuring fiber (ADF and NDF) and lipid (EE) digestibility, because each can have a large effect on GE digestibility. Carbon digestibility was also reported as some may want to use this information relative to some measure of C balance in the environment. Not surprisingly, C digestibilities (both the actual value and treatment effects) are very similar to GE digestibilities. Phosphorus digestibilities were reported relative to the effect of P excretion on the environment (Knowlton et al., 2004), whereas S digestibilities were reported relative to their potential effect on gas emissions (Le et al., 2005). Although total-tract N digestibilities are largely irrelevant to amino acid digestibility or use (Stein et al., 2007), total-tract N digestibility is a portion of the N excreted into the environment, which also affects the environmental quality (Kerr, 2003).

Some of the products evaluated in this study should have contained enzyme activities (i.e., β-glucanase, hemicellulose, protease, xylanase; Table 1) that could be helpful in improving energy, fiber, or nutrient digestibility in pigs fed diets containing 30% C-DDGS. Because we did not confirm the specified enzyme or active-ingredient activity for these additives, it may be possible that they did not contain enough activity relative to the fiber (substrate) level in the diet or the right type of activities to provide significant improvements in digestibility for many of the components evaluated. An independent laboratory was unable to be located from which the products could be analyzed for their various activities. Another possible reason for the lack of notable nutrient digestibility and growth performance responses may have been because of the source of C-DDGS included in the diet. Urriola et al. (2010) showed that apparent total-tract digestibility of dietary fiber can range from 23 to 55% among C-DDGS sources. Perhaps the single C-DDGS source used in this study was low in digestible fiber, and therefore, the ability of the products evaluated to affect nutrient digestibility could not be achieved. In addition, a more detailed characterization of "fiber," beyond that of NDF, may be needed to match enzymatic activity with a fiber structure digestion in future studies of this type. Finally, because these diets were formulated to meet the nutrient needs of pigs in each growth phase evaluated, the

Table 3. Coefficients of apparent total-tract digestibility in starter pigs fed diets containing exogenous feed additives[1]

Item	GE	N	C	S	P	ADF	NDF	Ether extract
Treatment[2]								
Control	0.79	0.80	0.80	0.79	0.60	0.40	0.37	0.64
Allzyme	0.77	0.78	0.77	0.78	0.56	0.31	0.27	0.62
P-value[3]	0.01	0.01	0.01	0.17	0.01	0.01	0.01	0.14
BactoCel	0.80	0.80	0.80	0.80	0.60	0.39	0.39	0.65
P-value[3]	0.14	0.55	0.42	0.03	0.79	0.76	0.15	0.66
BioPlus2B	0.80	0.80	0.80	0.80	0.59	0.38	0.35	0.65
P-value[3]	0.59	0.64	0.85	0.17	0.24	0.31	0.39	0.64
Econase	0.78	0.79	0.79	0.77	0.54	0.36	0.33	0.63
P-value[3]	0.07	0.07	0.10	0.04	0.01	0.06	0.03	0.45
Hemicel	0.79	0.79	0.80	0.79	0.60	0.36	0.33	0.66
P-value[3]	0.53	0.17	0.48	0.49	0.60	0.12	0.09	0.45
Porzyme	0.79	0.79	0.80	0.79	0.58	0.36	0.33	0.65
P-value[3]	0.67	0.47	0.61	0.66	0.16	0.13	0.07	0.67
Releezyme	0.77	0.77	0.78	0.77	0.56	0.30	0.30	0.61
P-value[3]	0.01	0.01	0.01	0.09	0.01	0.01	0.01	0.08
Rovabio	0.80	0.81	0.81	0.80	0.60	0.38	0.37	0.64
P-value[3]	0.12	0.25	0.14	0.06	0.61	0.39	0.97	0.88
Roxazyme	0.80	0.81	0.80	0.80	0.59	0.39	0.39	0.63
P-value[3]	0.40	0.10	0.42	0.06	0.38	0.58	0.16	0.61
XPC yeast	0.80	0.80	0.80	0.79	0.58	0.39	0.36	0.66
P-value[3]	0.40	0.81	0.46	0.26	0.06	0.63	0.95	0.33
Model								
P-value[4]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.08
SE[4]	0.004	0.005	0.003	0.005	0.008	0.017	0.013	0.012
Wk 1[5]	0.77	0.76	0.78	0.75	0.55	0.31	0.29	0.71
Wk 3	0.79	0.80	0.80	0.79	0.59	0.36	0.36	0.62
Wk 5	0.81	0.82	0.81	0.82	0.60	0.42	0.39	0.59
P-value[6]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
SE[6]	0.002	0.003	0.002	0.003	0.004	0.009	0.007	0.006

[1]Apparent total-tract digestibility calculated using indirect marker methodology. There were 16 to 18 individually fed pigs per dietary treatment.

[2]Allzyme SSF, 500 mg/kg (Alltech, Lexington, KY); BactoCel, 110 mg/kg (Lallemand Animal Nutrition, Milwaukee, WI); BioPlus 2B, 500 mg/kg (Chr. Hansen, Milwaukee, WI); Econase XT25, 150 mg/kg (AB Enzymes, Darmstadt, Germany); Hemicel, 500 mg/kg (ChemGen Corp., Gaithersburg, MD); Porzyme 9302, 250 mg/kg (Danisco Animal Nutrition, Marlborough, UK); Releezyme 4M, 500 mg/kg (Prince Agri Products Inc., Quincy, IL); Rovabio AP10, 500 mg/kg (Adisseo, Antony, France); Roxazyme G2G, 220 mg/kg (DSM Nutritional Products Inc., Parsippany, NJ); XPC yeast, 2,000 mg/kg (Diamond V Mills Inc., Cedar Rapids, IA).

[3]*P*-value represents comparison of the feed additive to the control diet only.

[4]Model *P*-value and SE value for overall diet effect.

[5]Initial, wk 1, wk 3, and wk 5 BW of 11.88, 13.96, 23.23, and 33.26 kg, respectively.

[6]Model *P*-value and SE value for week.

increases or decreases in nutrient digestibility that did occur may have been too small to influence overall pig performance.

The lack of consistency in responses from using feed additives, notably enzymes, in swine diets to improve nutrient digestibility and pig performance is common in the literature. Inborr et al. (1993) reported that adding a multienzyme complex (β-glucanase, xylanase, and amylase) to diets containing barley and wheat improved soluble non-starch polysaccharide digestibility in 10-kg pigs, but growth performance was unaffected. Similarly, Nonn et al. (1999) reported no effect of enzyme (β-glucanase, xylanase, and α-galactosidase) supplementation on pig growth performance, even though they observed increased digestibility of crude fiber and cellulose. Likewise, Thacker and Campbell (1999) and Carneiro et al. (2008) reported that enzyme supplementation (β-glucanase and pentosanase; and β-cellulase, β-glucanase, and β-xylanase, respectively) increased various nutrient digestibility coefficients, but there was

Table 4. Coefficients of apparent total-tract digestibility in finisher pigs fed diets containing exogenous feed additives[1]

Item	GE	N	C	S	P	ADF	NDF	Ether extract
Treatment[2]								
Control	0.81	0.84	0.82	0.83	0.39	0.53	0.42	0.47
Allzyme	0.82	0.84	0.83	0.83	0.47	0.57	0.47	0.48
P-value[3]	0.27	0.61	0.29	0.38	0.01	0.08	0.08	0.41
BactoCel	0.81	0.82	0.82	0.82	0.37	0.50	0.40	0.50
P-value[3]	0.40	0.05	0.57	0.73	0.36	0.19	0.34	0.11
BioPlus2B	0.82	0.83	0.83	0.83	0.39	0.56	0.45	0.39
P-value[3]	0.58	0.46	0.49	0.91	0.96	0.10	0.23	0.01
Econase	0.81	0.83	0.82	0.83	0.40	0.51	0.42	0.47
P-value[3]	0.40	0.15	0.45	0.55	0.75	0.33	0.95	0.82
Hemicel	0.81	0.83	0.82	0.82	0.37	0.48	0.37	0.44
P-value[3]	0.30	0.20	0.27	0.74	0.37	0.03	0.08	0.25
Porzyme	0.79	0.81	0.80	0.80	0.33	0.44	0.34	0.44
P-value[3]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.28
Releezyme	0.80	0.81	0.80	0.80	0.33	0.50	0.35	0.38
P-value[3]	0.01	0.01	0.01	0.01	0.01	0.18	0.02	0.01
Rovabio	0.81	0.84	0.82	0.83	0.36	0.53	0.44	0.46
P-value[3]	0.98	0.92	0.96	0.88	0.20	0.93	0.62	0.62
Roxazyme	0.81	0.82	0.82	0.82	0.37	0.50	0.38	0.50
P-value[3]	0.45	0.12	0.35	0.27	0.45	0.15	0.14	0.08
XPC yeast	0.80	0.83	0.81	0.82	0.36	0.50	0.38	0.43
P-value[3]	0.05	0.10	0.05	0.36	0.09	0.19	0.18	0.08
Model								
P-value[4]	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
SE[4]	0.005	0.006	0.005	0.005	0.015	0.015	0.020	0.014
Wk 1[5]	0.81	0.82	0.82	0.82	0.39	0.51	0.40	0.45
Wk 3	0.81	0.83	0.82	0.82	0.37	0.52	0.41	0.45
Wk 5	0.81	0.83	0.82	0.82	0.37	0.51	0.40	0.45
P-value[6]	0.43	0.17	0.39	0.17	0.78	0.62	0.96	0.89
SE[6]	0.002	0.003	0.002	0.003	0.003	0.008	0.010	0.007

[1]Apparent total-tract digestibility calculated using indirect marker methodology. There were 8 individually fed pigs per dietary treatment.

[2]Allzyme SSF, 500 mg/kg (Alltech, Lexington, KY); BactoCel, 110 mg/kg (Lallemand Animal Nutrition, Milwaukee, WI); BioPlus 2B, 500 mg/kg (Chr. Hansen, Milwaukee, WI); Econase XT25, 150 mg/kg (AB Enzymes, Darmstadt, Germany); Hemicel, 500 mg/kg (ChemGen Corp., Gaithersburg, MD); Porzyme 9302, 250 mg/kg (Danisco Animal Nutrition, Marlborough, UK); Releezyme 4M, 500 mg/kg (Prince Agri Products Inc., Quincy, IL); Rovabio AP10, 500 mg/kg (Adisseo, Antony, France); Roxazyme G2G, 220 mg/kg (DSM Nutritional Products Inc., Parsippany, NJ); XPC yeast, 1,000 mg/kg (Diamond V Mills Inc., Cedar Rapids, IA).

[3]*P*-value represents comparison of the feed additive to the control diet only.

[4]Model *P*-value and SE value for overall diet effect.

[5]Initial, wk 1, wk 3, and wk 5 BW of 98.40, 104.90, 119.52, and 132.20 kg, respectively.

[6]Model *P*-value and SE value for week.

little to no effect on pig growth performance. In contrast, Omogbenigun et al. (2004) supplemented an enzyme cocktail (cellulase, galactanase, mannase, and pectinase) to a wheat-based diet fed to 6-kg pigs and observed an improvement in growth performance over a 38-d period. Improved ileal and total-tract apparent digestibility of DM, CP, and GE has also been reported by Yin et al. (2000), who added xylanase to diets containing wheat by-products fed to 15-kg pigs, especially in diets containing higher levels of insoluble nonstarch polysaccharides by the addition of wheat bran. Furthermore, adding an enzyme cocktail (fermentation extracts and solubles from *Aspergillus niger* and *Trichoderma longibrachiatum*) to a diet containing 20% soy hulls improved DM and energy digestibility, but not N digestibility, in 33- to 51-kg pigs (Moeser and van Kempen, 2002). Recently, Emiola et al. (2009) reported that β-glucanase or β-xylanase addition to a diet containing wheat DDGS improved DM, N, GE, and fiber digestibility. In contrast, O'Shea et al. (2010) reported that addition

Table 5. Growth performance of pigs fed exogenous feed additives[1]

	Starter, 12 to 33 kg BW			Finisher, 98 to 132 kg BW		
Item	ADG, kg	ADFI, kg	G:F	ADG, kg	ADFI, kg	G:F
Treatment[2]						
Control	0.640	1.126	0.572	0.999	3.032	0.333
Allzyme	0.651	1.140	0.574	0.961	3.118	0.311
BactoCel	0.615	1.083	0.568	1.007	3.084	0.328
BioPlus2B	0.645	1.162	0.559	0.988	3.179	0.315
Econase	0.653	1.133	0.578	1.051	3.240	0.325
Hemicel	0.629	1.149	0.551	0.933	3.239	0.292
Porzyme	0.642	1.131	0.570	0.979	3.077	0.318
Releezyme	0.639	1.109	0.579	0.983	3.115	0.311
Rovabio	0.648	1.148	0.565	0.906	2.985	0.302
Roxazyme	0.638	1.100	0.583	0.975	3.084	0.321
XPC yeast	0.653	1.157	0.568	0.862	2.930	0.294
Model						
P-value	0.87	0.70	0.72	0.60	0.90	0.56
SE	0.016	0.030	0.011	0.057	0.141	0.014

[1]Performance over the 5-wk period. There were 16 to 18 and 8 individually fed pigs per treatment in the starter and finisher phase, respectively.

[2]Allzyme SSF, 500 mg/kg (Alltech, Lexington, KY); BactoCel, 110 mg/kg (Lallemand Animal Nutrition, Milwaukee, WI); BioPlus 2B, 500 mg/kg (Chr. Hansen, Milwaukee, WI); Econase XT25, 150 mg/kg (AB Enzymes, Darmstadt, Germany); Hemicel, 500 mg/kg (ChemGen Corp., Gaithersburg, MD); Porzyme 9302, 250 mg/kg (Danisco Animal Nutrition, Marlborough, UK); Releezyme 4M, 500 mg/kg (Prince Agri Products Inc., Quincy, IL); Rovabio AP10, 500 mg/kg (Adisseo, Antony, France); Roxazyme G2G, 220 mg/kg (DSM Nutritional Products Inc., Parsippany, NJ); XPC yeast, 2,000 mg/kg starter or 1,000 mg/kg finisher (Diamond V Mills Inc., Cedar Rapids, IA).

of a β-glucanase or β-xylanase mix to barley- or oat-based diets increased total-tract digestibility of N but had no effect on DM, OM, GE, NDF, or ash digestibility in finishing pigs.

In corn–soybean meal–based diets, addition of β-glucanase had no effect on CP, DM, or GE digestibility in 6-kg pigs (Li et al., 1996). Likewise, supplementation of β-mannanase to a corn–soybean meal–based diet improved feed efficiency in pigs weighing less than 15 kg but failed to show any effect on DM, GE, or N digestibility in 93-kg barrows and had no effect on carcass composition when fed from 23 to 110 kg BW (Pettey et al., 2002). Kim et al. (2003) used a carbohydrase enzyme mixture (α-1,6-galactosidase and β-1,4 mannanase) in corn–soybean meal–based diets fed to pigs weighing less than 20 kg of BW and reported an improvement in ileal GE digestibility and feed efficiency. In a similar manner, supplementation of enzyme preparations (combinations of cellulase, galactanase, mannanase, or pectinase) added to corn- and soybean meal–based diets (which also contained small amounts of wheat, wheat screenings, barley, millrun, canola meal, and peas) and fed to 7-kg pigs improved various digestibilities (DM, starch, GE, CP, nonstarch polysaccharides, and phosphorus) in both the ileum and total tract as well as overall growth performance (Omogbenigun et al., 2004). Recently, Ji et al. (2008) evaluated a β-glucanase–protease enzyme blend added to a corn–soybean meal diet in 38-kg pigs and reported an increase in total-tract digestibility of CP, DM, GE, P, and total dietary fiber but only observed an increase in ileal digestibility of NDF. These authors suggested that the increase in ileal NDF digestibility, with no change in fecal digestibility because of enzyme supplementation, may have shifted some of the digestion of these nutrients from the hindgut to the small intestine, which would avoid the fermentative loss of energy and presumably increase the energetic efficiency of fiber digestion.

Data showing whether addition of dietary enzymes will enhance growth performance in finishing pigs fed diets containing increased levels of corn fiber are scarce. Fiber in corn has not been particularly well characterized, but in general it can be considered as largely insoluble as suggested by similar NDF and TDF analytical values. In addition, the insoluble dietary fiber contains a high percentage of hemicelluloses relative to cellulose (Anderson et al., 2012; NRC, 2012). We did not analyze the specific sample of C-DDGS used in this project nor did we analyze for nonstarch polysaccharides. Spencer et al. (2007) reported that adding an enzyme preparation (β-glucanase, α-galactosidase, galactomannanase, and xylanase) to diets containing 30% C-DDGS increased growth performance in nursery pigs, but no change in nursery pig per-

formance was reported by Jones et al. (2010) in diets also containing 30% C-DDGS and the use of similarly composed commercial enzymes (various activities of β-glucanase, α-galactosidase, galactomannanase, and xylanase). Jacela et al. (2010) reported that various commercially available enzymes in diets based on corn, soybean meal, and C-DDGS did not enhance finishing-pig performance, whereas Yoon et al. (2010) reported improved gain and nutrient digestibility in growing-finishing pigs when a β-mannanase was supplemented to diets containing up to 15% C-DDGS.

Although several authors have reported that yeast and yeast products have a positive effect on nutrient metabolism (Spark et al., 2005), immune system modulation (Shen et al., 2009), gut microbial populations (Mathew et al., 1998; van der Peet-Schwering et al., 2007; Shen et al., 2009), and growth performance (Mathew et al., 1998; van der Peet-Schwering et al., 2007; Shen et al., 2009), the results have been inconsistent. Other researchers have reported that yeast or yeast cultures have little to no positive effect on nutrient digestion (Kornegay et al., 1995; van Heugten et al., 2003), measures of immune responses (Sauerwein et al., 2007; van der Peet-Schwering et al., 2007), gastrointestinal microbial populations (van Heugten et al., 2003), or nursery pig performance (White et al., 2002; van Heugten et al., 2003). Furthermore, it is noteworthy that up to 20% of the protein in C-DDGS may be from yeast, equating to 7% of the C-DDGS by weight (Han and Liu, 2010; Liu, 2011). Given that we added 30% C-DDGS to the experimental diets, this would equate to approximately 2% yeast in the diet, and as such, we had no expectations that the further addition of yeast of 0.2 and 0.1% in the nursery and finisher diets, respectively, would affect digestibility measures or performance. Data from the current experiment support this inference because few changes in nutrient digestibility coefficients in either nursery or finisher pigs were noted and there was no effect on pig performance in either phase of growth.

Direct-fed microbials have also been used to modulate gastrointestinal bacterial populations in an effort to improve pig performance. Feeding *Enterococcus faecium* (Taras et al., 2006; Zeyner and Boldt, 2006) or lactic acid–producing bacteria (Apgar et al., 1993; Zani et al., 1998; Kyriakis et al., 1999) to nursery pigs, and *Bacillus* organisms to growing pigs (Davis et al., 2008) have been shown to reduce postweaning diarrhea or improve growth performance. No data are available for pigs fed diets using high levels of C-DDGS and containing direct-fed microbials. Results from the current experiments indicate that BioPlus2B and BactoCel have little effect on the digestibility coefficients in either nursery or finisher pigs and have no effect on pig performance when they are added at recommended levels to diets containing 30% C-DDGS.

In the current study, only one product contained phytase activity (300 phytase units/g), and the results were inconsistent between the 2 age groups of pigs evaluated. Supplementation of the phytase containing product (Allzyme) decreased P digestibility in nursery pigs, but increased P digestibility in finishing pigs. This was not expected and was contrary to the literature where Xu et al. (2006a,b) reported that the addition of 500 phytase units/kg of feed improved P digestibility in diets containing 20% C-DDGS in starter and finisher pigs. The current results for phytase (Allzyme) also differ from those by Lindemann et al. (2009), who reported that 64- to 123-kg pigs fed diets containing 20% C-DDGS supplemented with 250 or 500 phytase units/kg of feed exhibited greater DM, GE, and N digestibility than did unsupplemented pigs. In the current study, however, only 165 phytase units were added per kilogram of feed, which may be too low for an effect to be observed.

In reviewing the changes (be they positive or negative) in digestibility coefficients of energy or nutrients in the current experiment as a whole as shown in Tables 3 and 4 to the lack of an effect on animal performance as shown in Table 5, one has to question why the differences in digestibility did not translate into changes in growth performance. Concerning this, one must consider that there are always errors associated with response measures and finding differences that are deemed significant, or lack thereof; in either digestibility or performance experimentation there is some degree of error. Relative to the current data, if one assumes that the changes in digestibility are real (i.e., they were significant), in the overall digestion and metabolism of energy nutrients into animal performance (as measured by gain, feed intake, and feed efficiency), the changes in digestibility are either (1) not great enough to elicit a pig performance response or (2) the current experimental methodology, which is adequate for measuring digestibility differences, is not sensitive enough to measure expected changes in pig performance. In reviewing metabolism and digestion experiments in the literature, these experiments are commonly conducted with pigs fed individually, with little weight given to their performance levels compared with group-fed pigs. It is noteworthy, however, that others as cited previously have reported that changes in nutrient or energy digestibility do not necessarily result in changes in pig performance or that changes in pig performance have been noted with no changes in energy or nutrient digestibility.

IMPLICATIONS

These results imply that improvements in nutrient digestibility and pig performance from adding exogenous feed additives to growing-pig diets depend on a better understanding of the diversity and concentration of chemical characteristics of plant-based feed ingredients in relation to enzyme activity, gastrointestinal microflora, and immune function. Although the results of this research indicate that some of the feed additive products evaluated had variable but small effects on nutrient digestibility, none

of these products were effective in improving starter- and finishing-pig growth performance when fed nutritionally adequate corn–soy diets containing 30% C-DDGS.

ACKNOWLEDGMENTS

The authors are thankful for help from J. Cook at the USDA-ARS for laboratory assistance. The National Pork Board (Des Moines, IA) provided financial support for this research. Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the USDA or the University of Minnesota and does not imply approval to the exclusion of other products that may be suitable. The USDA is an equal opportunity provider and employer.

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