ENZYMES FOR USE IN HIGH DDGS SWINE DIETS

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I. INTRODUCTION

Plant carbohydrates can be classified into three categories: 1) simple sugars and their conjugates (glucose, fructose, etc.); 2) storage reserve compounds (starch); and 3) structural carbohydrates (cellulose, hemicellulose, etc.). Simple sugars and storage compounds are primarily digested in the upper gastrointestinal tract, although not completely, while structural carbohydrates are only partially degraded by the microflora in the cecum and large intestine (Slominski, 1991). Because most of the starch is removed from corn during ethanol production, the resultant co-product, dried distillers grains with solubles (DDGS), contains concentrated levels of protein, minerals, and fiber (Spiehs et al., 2002; Pedersen et al., 2007; Anderson, 2009). With pigs being able to utilize moderate, but not high levels of fiber in the nursery (Whitney and Shurson, 2004; Weber et al., 2008) and finisher (Whitney et al., 2006) period, there is a need to increase the ability of the pig to utilize the energy associated with the structural carbohydrates contained in corn-derived co-products (Muley et al., 2007). With the large amount of corn being utilized for ethanol production in the U.S., the amount of high fiber corn co-products available for animal feeds continues to increase. In order to minimize the cost associated with dietary energy and amino acids, it is essential that we develop and evaluate technologies that increase digestibility of energy and other nutrients. Use of exogenous enzymes is one of these technologies that offer promise for improving the nutritional value of high fiber corn co-products, particularly DDGS.

II. "FIBER" IN SWINE NUTRITION

A. Definition

Unfortunately, "fiber" is perhaps the most poorly understood constituent of swine diets, and is generally described as a complex and highly variable component of plant-based feedstuffs (Figure 1, NRC, 2007). It is important to note that the analytical methods used to characterize "fiber" often overlap or exclude fractions of other distinctly different carbohydrate fractions in a feedstuff, and consequently, our ability to adequately relate analytical measures to fiber utilization has been problematic. Some fiber types are more digestible than others, and although they cannot be broken down by mammalian enzymes, they can be fermented by bacteria in the hindgut (Grieshop et al., 2001). These fiber types are often termed "nonstarch polysaccharides" (NSP), where up to 90% of the cell walls of plants are made up of NSP; of which, cellulose, hemicellulose, and pectins are most abundant (Selvendran and Robertson, 1990). Other less abundant NSP include fructans, glucomannans, galactomannans, mucilages, β-glucans, and gums. Cellulose is found in tightly bound aggregates in plants, while hemicellulose and pectins have sugar side chains that allow them to be more readily broken down. Lignin is not a polysaccharide per se, but is a high molecular weight polymer, and is not considered a functional dietary constituent because it is indigestible by swine (Grieshop et al., 2001).

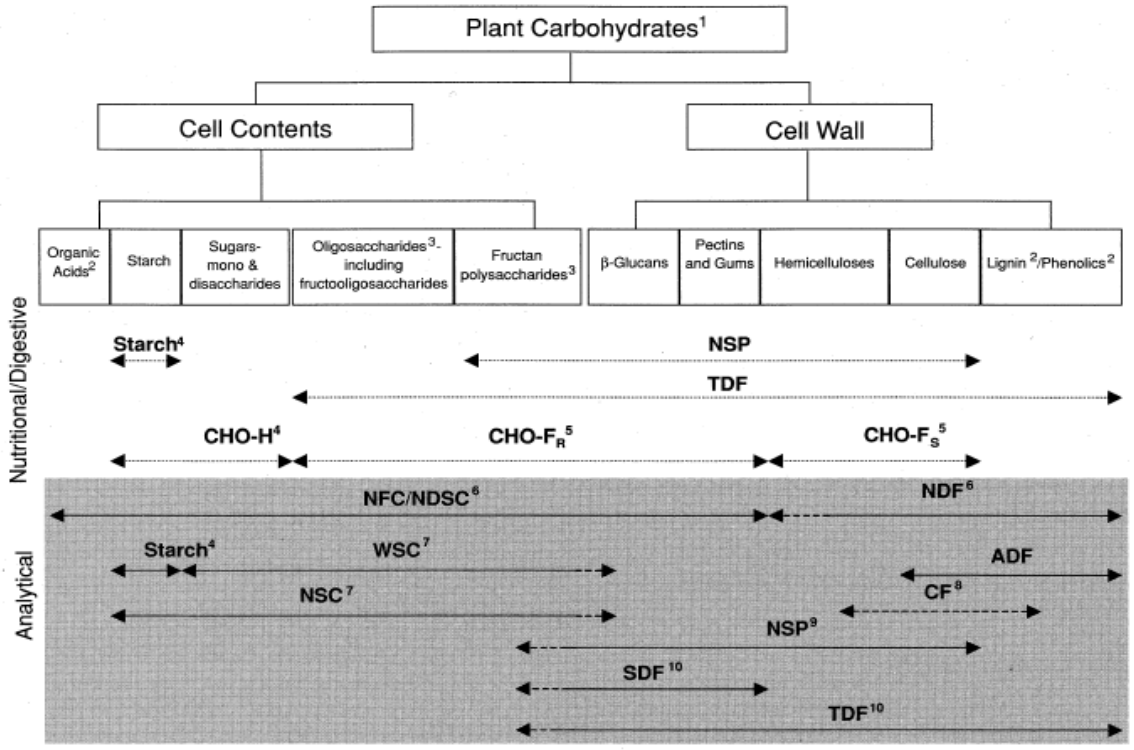

FIGURE 10-1 Fractionation of plant carbohydrates and related compounds

Current and proposed systems for partitioning dietary carbohydrates based on current analytical methods (lower/shaded bracket; solid/dashed lines) and nutritional or physiologic definitions (upper bracket; dotted lines) relative to equine digestive function. Adapted from Hall, 2003 and Hoffman, 2004. In the analytical bracket, dashed lines indicate that recovery of included compounds may be incomplete.

Abbreviations: ADF = acid detergent fiber; CF = crude fiber; CHO-H = hydrolyzable carbohydrates; CHO-F_S = slowly fermentable carbohydrates; CHO-F_R = rapidly fermentable carbohydrates; NDF = neutral detergent fiber; NDSC = neutral detergent soluble carbohydrates; NFC = nonfiber carbohydrates; NSC = nonstructural carbohydrates; NSP = nonstarch polysaccharides; SDF = soluble dietary fiber; TDF = total dietary fiber; WSC = water-soluble carbohydrates

[1]Major categories of carbohydrates and associated substances are shown. These categories may not include all carbohydrates produced by plants.
[2]Some noncarbohydrate components are included here as they are components of the specific analytical fractions.
[3]Specific fructans can be categorized as either fructooligosaccharides or fructan polysaccharides depending on degree of polymerization.
[4]A variable fraction of total starch can be resistant to enzymatic hydrolysis and thus some starch may appear in other nutritional fractions.
[5]Fermentability of gums may be variable.
[6]Some hemicellulose may be soluble in neutral detergent and thus recovered in the NFC/NDSC fraction, rather than the NDF fraction.
[7]Recovery of compounds in the analytical WSC fraction (and thus the NSC fraction when NSC is approximated as starch + WSC) may depend on methodology used.
[8]Amount of cell wall constituents included in CF analysis varies by feed.
[9]From a nutritional perspective, NSP includes all polysaccharides except starch. However, the analytical method for NSP may recover a variable amount of fructan polysaccharide.
[10]From a nutritional perspective, TDF includes all carbohydrates resistant to mammalian digestion. However, the analytical method for TDF (and SDF) does not recover oligosaccharides and may recover a variable amount of fructan polysaccharides.

Figure 1. Nutritional and analytical classifications used to characterize plant carbohydrates.

As shown in Figure 1, common analytical methods used to measure complex carbohydrates in high fiber feed ingredients and feeds include: crude fiber, acid detergent fiber (ADF), neutral detergent fiber (NDF), soluble and insoluble fractions of total dietary fiber (TDF), and NSP.

Each of these fiber methods measures several fractions of complex carbohydrates, but they do not adequately relate to the energy value of feeds for swine.

B. Energy value of fiber

The digestibility of "fiber" in swine diets can vary drastically between 0 and 97% depending upon the source of fiber (Bach Knudsen and Hansen, 1991), processing method (Fadel et al., 1989), and concentration in the diet (Stanogias and Pearce, 1985; Goodlad and Mathers, 1991). However, many NSP are partially fermentable in the hindgut and can be used to produce volatile fatty acids (VFA) such as acetate, propionate, and butyrate. These VFA are rapidly absorbed and have been shown to supply between 5 and 28% maintenance energy requirement of the pig (Farrell and Johnson, 1970; Imoto and Namioka, 1978; Kass et al., 1980; Latymer and Low, 1987; Rérat et al., 1987; Yen et al., 1991). However, the loss of energy due to methane, hydrogen, and fermentation heat decrease the amount of energy available to the pig from fermentation of fiber in the hindgut (Grieshop, 2001), thereby decreasing the efficiency of energy utilization (Giusi-Perier et al., 1989, Noblet et al., 1994).

C. Fiber alters the gastrointestinal tract

1. Weight
   Feeding high fiber diets results in a general increase in the total empty weight of the gastrointestinal tract (Kass et al., 1980; Stanogias and Pearce, 1985; Anugwa et al., 1989) and increased gastrointestinal secretions (Grieshop et al., 2001). Jørgensen et al. (1996) showed that growing-finishing pigs fed diets containing high dietary fiber (NSP + lignin) (268 g/kg dry matter, DM) as compared to pigs fed diets low in dietary fiber (59 g/kg DM), had a significantly heavier stomach, cecum, and colon weights, as well as a longer colon.

2. Enterocyte proliferation
   Intestinal epithelial cell proliferation rate is stimulated by high NSP diets (Jin et al., 1994; Howard et al., 1995) leading to an increase in cell turnover rate. Growing pigs fed diets containing 10% wheat straw had a 33% increase in the rate of jejunal and colonic cell proliferation, and a 65% increase in cells undergoing cell death (Jin et al., 1994).

3. Endogenous fluid secretion
   The secretion of endogenous fluids is also increased when feeding high fiber diets to pigs (Wenk, 2001). Secretions of saliva, gastric juice, and pancreatic juice were doubled when dietary fiber content was increased from 50 to 180 g/kg in 50 kg pigs (Zebrowska et al., 1983).

4. Maintenance energy requirement
   With the many changes in the characteristics of the gastrointestinal tract due to feeding a high fiber diet, the maintenance energy requirements of pigs may be increased by the extra metabolic demand due the nutrient needs for visceral organ development and maintenance (Grieshop et al., 2001; Wenk, 2001). Consequently, methods to improve fiber digestion would reduce these negative effects of fiber on animal metabolism.

5. Gastric emptying and satiety

   The rate of gastric emptying may decrease with the addition of certain forms of NSP. Guar gum and pectin increase the viscosity of the digesta (Grieshop et al., 2001) and water retention (Johansen et al., 1996). Growing pigs fed a high energy (starch, casein, soybean oil, and tallow) diet supplemented with 40 to 60 g/kg guar gum had a reduced rate of gastric emptying of 33 to 52% after feeding, and a 27% reduction in DM concentration of the digesta (Rainbird, 1986; Rainbird and Low, 1986). High fiber diets may also contribute to earlier satiety resulting from gastric signals due to the elongation of the stomach wall. Feeding an increased amount of dietary fiber may lead to increased volume of digesta in the stomach, decreased transit time, and increased satiety. This is important in gestating sows where it has been shown that sows satisfied physically and nutritionally appeared to be less stressed and exhibited decreased physical activity (Rijhen et al., 1999).

6. Digesta passage rate and nutrient utilization

   The passage rate of digesta can also be affected by feeding diets high in fiber. Some studies have shown increasing daily DM flow at the terminal ileum when increasing levels of NDF were added to the diet (Schulze et al., 1995). Others have also shown up to a 14 and 23% increase in rate of passage when 75 to 300 g of bran or oatmeal by-products, respectively, was added to the diet (Potkins et al., 1991). These results suggest that the differences in rate of passage through the total digestive tract may be due to differences in the rate of passage through the large intestine, because neither fiber source had a significant effect on gastric emptying or passage through the small intestine (Potkins et al., 1991). Additionally, particle size of the fiber source may also contribute to the rate of passage. Bardon and Fioramonti (1983) showed that a coarser particle size of wheat bran decreases transit time compared to a finer particle size.

   The amount of time the digestive contents spend in the large intestine can also affect the capacity for fermentation. Fiber fermentation in the cecum and colon results in the production of VFA, mainly acetic, propionic, and butyric acids which are viable sources of energy. However, the energy density and digestibility of the diet usually decreases with the addition of NSP (Grieshop et al., 2001). In addition, NSP reduces lipid absorption due to a partial inhibition of both lipolysis and intestinal fat absorption (Borel et al., 1989). Nonstarch polysaccharides also decrease dietary nitrogen (N) retention due to increased secretion of endogenous N, which leads to increased bacterial N excretion (Grieshop et al., 2001). Although minerals do not contribute energy directly to the diet, an impact of NSP on mineral utilization should also be considered (i.e., deficiencies or excesses could lead to physiological conditions that may ultimately affect energy absorption). However, the impact of NSP sources on mineral utilization appears to be minimal (Kornegay and Moore, 1986; Grieshop et al., 2001).

III. MECHANICAL PROCESSING EFFECTS ON FIBER UTILIZATION

Data pertaining to the effect of corn and corn co-product processing (mechanical or chemical) on changes in fiber utilization in non-ruminants is lacking or inconsistent. Teitge et al. (1991) reported that pelleting and micronizing, but not steam-flaking, resulted in a greater response to a dietary pentosanase in broilers fed diets containing rye, while Brenes et al. (1993a) indicated that autoclaving lupins had no impact on chick performance. Autoclaving high-tannin peas, in contrast to low-tannin peas, improved apparent metabolizable energy and apparent protein digestibility in Leghorn chicks (Brenes et al., 1993b). In 80 kg pigs fed barley-based diets, pelleting had no effect on ileal or fecal apparent digestibilities of DM, energy, crude protein (CP), fat, or fiber (NSP + lignin), although it did increase pre-ileal apparent digestibility of starch (Graham et al., 1989). In contrast to Teitge et al. (1991), Graham et al. (1989) reported that pelleting did not improve the digestibility response found when dietary ß-glucanase was added to the diet.

Poel et al. (1992) reported that steam processing of faba bean cotyledons did not improve ileal digestibility of CP, either due to the low level of trypsin inhibitor activity present in faba beans, or due to the trypsin inhibitor being sensitive to heat above the 100º C which was used in this study. Likewise, Thacker and Campbell (1999) and Nyachoti et al. (2006) showed little effect of micronization on nutrient digestibility coefficients. Pelleting of diets containing high levels of corn fiber (corn gluten feed), improved N balance, apparently due to the increased availability of tryptophan (Yen et al., 1971). Extrusion is a common heat processing method for feed ingredients used in the commercial feed industry. However, very little is known about the effects of extruding corn and corn co-products on nutritional value (Muley et al. 2007). Therefore, studies are needed to assess the effects of extrusion and other practical feed processing methods of high fiber corn co-products on nutrient digestibility in pigs.

IV. EFFECTS OF EXOGENOUS ENZYMES ON FIBER UTILIZATION

A. Poultry vs. swine diets

The addition of exogenous enzymes to animal feeds in efforts to improve nutrient digestion is not a new concept and responses have been reviewed in detail (Chesson, 1987; Bedford, 2000). The majority of commercial enzyme products have been targeted toward poultry (Annison and Choct, 1991; Cowan, 1993) and are typically added to diets containing barley, oats, peas, rye, or wheat (Aimonen and Nasi, 1991; Thacker et al., 1992; Viveros et al., 1994; Huberner et al., 2002), with only limited research evaluating enzyme use in corn-soybean meal diets (Saleh et al., 2005).

B. Enzymes in non-corn based swine diets

Like poultry, the majority of research on adding enzymes to swine diets has focused on non-corn-based diets. Adding a multi-enzyme complex to diets containing barley and wheat has been shown to improve soluble NSP digestibility in 10 kg pigs, although growth performance was not affected (Inborr et al., 1993). Similarly, variation in responses from enzyme addition in pig diets has also been reported by Nonn et al. (1999), who found no effect of enzyme supplementation on

pig growth performance, even though they observed increased digestibility of crude fiber and cellulose. Likewise, Thacker and Campbell (1999) indicated that although enzyme supplementation increased nutrient digestibility coefficients, there was little effect on pig growth performance. In contrast, Omogbenigun et al. (2004) supplemented an enzyme cocktail (cellulose, galactanase, mannase, and pectinase) to a wheat-based diet fed in 6 kg pigs and observed an improvement in growth performance (growth rate and feed efficiency) over a 38 d period. Improved nutrient digestibility has also been reported by Yin et al. (2000) who added xylanase to diets containing wheat by-products fed to 15 kg pigs and reported improved ileal and total tract apparent digestibility of DM, CP, and energy, especially in diets containing high levels of insoluble NSP. Lastly, adding an enzyme cocktail (fermentation extracts and soluble from *A. niger* and *T. longibranchautum*) 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). With soybean hulls having a large proportion of cellulose relative to other NSP, these data provide some evidence that cellulose digestion can be impacted in addition to hemicellulose and the more soluble forms of fiber.

C. Enzymes in corn-based swine diets

Limited research has been reported on the impact of exogenous enzymes on nutrient digestibility or pig performance when pigs are fed corn-based diets. Supplementation of β-glucanase to a corn-soybean meal-based diet had no impact on DM, energy, or CP digestibility in 6 kg pigs (Li et al., 1996). Likewise, supplementation of β-mannanase (β-mannase is a part of hemicellulose) to a corn-soybean meal-based diet failed to show any effect on DM, energy, or N digestibility in 93 kg barrows (Petty et al., 2002). However, adding β-mannanase improved feed efficiency in 6 kg pigs (42 d feeding period) and 14 kg pigs (21 d feeding period), and improved gain and feed efficiency, but had no impact on carcass composition, when fed from 23 to 110 kg (Pettey et al., 2002). Kim et al. (2003) utilized a carbohydrase enzyme mixture (α-1,6-galactosidase and β-1,4 mannanase) in corn-soybean meal-based diets fed to nursery pigs and reported an improvement in feed efficiency in two trials (35 d trial, 6.3 to 19.1 kg BW; and a 21 d trial, 8.0 to 15.2 kg BW) and ileal energy digestibility. Supplementation of the carbohydrase enzyme mixture also decreased the concentration of stachyose in the proximal and distal small intestine, and raffinose concentration in the distal small intestine, suggesting that this carbohydrase mixture improved the digestibility of the carbohydrates in soybean meal. In a similar manner, supplementation of several multi-enzyme preparations added to corn and soybean meal-based diets (small amounts of wheat, wheat screenings, barley, millrun, canola meal, and peas) fed to 7 kg pigs for 28 d, improved growth performance and various nutrient digestibility indices in both the ileum and total tract (Table 1; Omogbenigun et al., 2004).

Table 1. Effect of enzyme supplementation on growth performance, percent apparent ileal digestibility (AID), and total-tract digestibility (TTD) of nutrients in 7 kg pigs.[1]

	Diet[2]				Statistics	
Performance	Control	C + Enz A	C + Enz B	C + Enz C	SEM	P-value
ADG, g	224[b]	252[a]	263[a]	249[a]	7.9	0.02
ADFI, g	432	435	456	414	17.8	0.42
G:F	0.52[b]	0.58[a]	0.58[a]	0.61[a]	0.02	0.01
AID, %						
DM	60.1[b]	65.8	66.1[a]	66.7[a]	1.5	0.01
Starch	86.7[b]	92.6[a]	94.6[a]	95.3[a]	1.1	0.02
GE	62.8[b]	70.0[a]	69.7[a]	71.4[a]	0.9	0.01
CP	62.1[b]	71.5[a]	71.4[a]	73.2[a]	1.5	0.01
Phytate	59.2[b]	71.7[a]	69.1[a]	69.7[a]	2.3	0.04
NSP	10.1[b]	14.9[a]	16.4[a]	21.4[a]	1.4	0.01
TTD, %						
DM	75.6[b]	78.1	77.2[a]	80.0[a]	0.5	0.01
Starch	94.4[b]	98.6[a]	97.6[a]	98.6[a]	0.7	0.01
GE	77.8[b]	79.8[a]	79.8[a]	81.1[a]	0.7	0.01
CP	67.1[b]	71.2[a]	71.6[a]	74.2[a]	1.0	0.01
Phytate	69.4[b]	96.8[a]	96.3[a]	96.0[a]	3.2	0.01
NSP	48.9[b]	61.2[a]	59.6[a]	66.8[a]	1.2	0.01

[1]Average initial weight, 7.0 kg, 28 d trial, 6 pigs/trt, ADFI on a DM basis. (Omogbenigun et al., 2004)

[2]Enzyme preparations provided 250 units xylanase, 150 units glucanase, 0.001% amalyase, 0.0003% protease, 0.002% invertase, and 400 units phytase per kilogram of diet and differed in the type of plant cell wall degrading activities. Enzyme A contained cellulase, galactanase, and mannanase; Enzyme B contained cellulose and pectinase; and Enzyme C contained cellulose, galactanase, mannanase, and pectinase.

[abc]Means within a row with different superscripts differ at the P-value shown.

Recently, Ji et al. (2008) evaluated a β-glucanase-protease enzyme blend added to a corn-soybean meal diet and fed to 38 kg pigs (Table 2). Pigs fed the enzyme blend diet had increased total tract digestibility of DM, energy, CP, TDF, and phosphorus (P), but only increased ileal digestibility of NDF, while CP appeared to have decreased ileal digestibility. The authors suggested that the increase in ileal NDF digestibility (and hemicellulose), with no change in fecal digestibility due to 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.

Table 2. Effect of enzyme supplementation on percent apparent ileal digestibility (AID) and total-tract digestibility (TTD) of nutrients in 38 kg pigs.[1]

		Diet[2]		Statistics	
AID, %	Basal	B + 0.05%	B + 0.10%	B vs Enz	0.05 vs 0.10
DM	70.86	69.13	70.50	0.33	0.25
Energy	70.93	69.48	70.71	0.44	0.31
CP	78.29	75.51	76.54	0.04	0.37
Starch	97.95	98.01	98.12	0.51	0.59
NDF	1.21	9.52	10.05	0.02	0.88
ADF	4.33	4.36	5.22	0.91	0.84
TDF	NA	NA	NA	NA	NA
Crude fat	61.40	62.94	62.18	0.49	0.68
P	49.62	49.54	49.00	0.86	0.80
TTD, %					
DM	87.42	88.61	88.50	0.01	0.62
Energy	86.51	87.42	87.26	0.01	0.51
CP	86.47	88.08	87.39	0.01	0.10
Starch	99.24	99.26	99.31	0.53	0.44
NDF	54.62	55.62	56.05	0.36	0.77
ADF	64.84	61.40	65.92	0.40	0.01
TDF	60.61	65.36	65.61	0.01	0.86
Crude fat	80.14	80.51	78.24	0.51	0.09
P	53.80	61.73	57.83	0.01	0.01

[1]Average initial weight, 38.2 kg, 4×4 Latin Square with 14 d periods (4 d adapt, 5 d fecal collection, 3 d transition, 2 d ileal collection). (Ji et al., 2008)

[2]Enzyme contained 660 β-glucanase units/g and 22 hemoglobin units/g.

Recently, it has been reported that adding an enzyme preparation to diets containing 30% DDGS increased growth performance in nursery pigs (Spencer et al., 2007). Whether addition of dietary enzymes will enhance growth performance in finishing pigs fed diets containing increased levels of corn fiber remains unknown. Unfortunately, the results of studies where there are no effects of supplemental enzymes on pig growth performance go largely unreported in the scientific literature, which has led to a paucity of peer-reviewed data being available to pork producers, swine nutritionists, and other pork industry professionals.

V. PHYTASE ALONE, AND IN COMBINATION WITH OTHER ENZYMES

The impact of dietary phytase supplementation on the digestibility of energy has not been consistent. While most studies (Adeola et al., 2004, 2006; Liao et al., 2005; Jendza et al., 2006; Beaulieu et al, 2007) have observed no impact of phytase on energy digestibility, others (Brady et al., 2002; Shelton et al., 2003; Jendza et al., 2005; Veum et al., 2006) have reported positive effects. Recent results from Kerr et al. (2010) were also inconclusive, suggesting that if there is an effect of phytase on energy digestibility, it is relatively small in magnitude and highly variable.

The impact of phytase, with or without other enzymes, on nutrient (and energy) digestibility is lacking. Olukosi et al. (2007) supplemented diets comprised of corn, wheat midds, soybean meal, and canola meal with either phytase or an enzyme cocktail (xylanase, amylase, and protease) alone, or in combination, and fed them to 10 to 23 kg pigs (Table 3). These data suggest that even though phytase improved pig gain and feed efficiency, addition of the enzyme cocktail, alone or in combination with phytase, had no impact on pig performance. Neither the addition of phytase nor the enzyme cocktail, alone or in combination, had any consistent effect on DM, energy, or N digestibility, but each improved P digestibility. The effects, however, were not additive. In an additional experiment with wheat replacing corn in the diet (23 to 52 kg BW, 42 d trial), there were no effects of phytase or xylanase (500 U and 4,000 U/kg, respectively) on pig performance, or on N and energy digestibility (Olukosi et al., 2007). Phytase, but not xylanase, improved phosphorus digestibility.

Table 3. Growth performance and apparent total tract digestibility of 10 to 23 kg pigs receiving phytase, or a cocktail of xylanase, amylase, and protease.[1]

	Pig performance			Apparent total tract digestibility, %			
Dietary treatment	ADG, g	ADFI, g	G:F, g:kg	DM	GE	N	P
Negative control	398	1140	363	80.2	79.8	80.1	38.3
NC + Phytase[2]	483	1070	457	80.1	78.1	80.2	49.9
NC + Enzyme[3]	393	1050	380	82.3	80.1	81.2	48.3
NC + Ph + En	479	1210	415	80.0	79.0	80.0	51.1
SEM	10.4	30	13.7	0.20	0.43	0.43	0.87

[1] There were 4 replicate pens each of barrows and gilts (1 pig/pen) in the 28 d trial.
[2] Phytase was added at the rate of 500 phytase units/kg diet.
[3] Cocktail of 400 U of xylanase, 4,000 U of amylase, and 2,500 U of protease per kg of diet.

Results from experiments evaluating the impact of phytase, with or without other enzymes, on nutrient (and energy) digestibility in diets containing DDGS are also lacking and inconsistent. While addition of 500 units phytase improved P digestibility in diets containing 20% DDGS in starter or finisher pigs, it did not improve DM digestibility (Xu et al., 2006a,b). In contrast, Lindemann et al. (2009) reported that 64 to 123 kg pigs fed diets containing 20% DDGS supplemented with 250 or 500 U/kg phytase exhibited greater DM, energy, and N digestibility than unsupplemented pigs, but there were no further improvements in fecal DM, energy or N digestibility with additional xylanase supplementation.

VI. ENERGY AND FIBER IN CORN CO-PRODUCTS

Gross energy (GE) in DDGS averages 5,434 kcal/kg DM and is greater than the concentration of GE in corn (Table 4; Stein and Shurson, 2009). However, the digestibility of energy, measured as a percentage of GE, is lower in DDGS than in corn (Stein and Shurson, 2009). The DE and ME content of DDGS is 4,140 and 3,897 kcal/kg DM, respectively (Pedersen et al., 2007). These values are similar to the DE and ME content in corn (Table 4). The net energy value of DDGS has not been determined, but research is currently being conducted to measure these values.

Table 4. Concentration of energy in corn and 10 sources of corn distillers dried grains with solubles (DDGS) fed to growing pigs.[1]

		DDGS			
Item	Corn	Average	SD	Lowest value	Highest value
GE, kcal/kg DM	4,496	5,434	108	5,272	5,592
ATTD[2] of energy, %	90.4	76.8	2.73	73.9	82.8
DE, kcal/kg DM	4,088	4,140	205	3,947	4,593
ME, kcal/kg DM	3,989	3,897	210	3,674	4,336

[1] Data from Pedersen et al. (2007) (Adapted from Stein and Shurson, 2009).
[2] ATTD = apparent total tract digestibility.[2]

Since most of the starch in corn is converted to ethanol, DDGS contains approximately 35% insoluble and 6% soluble dietary fiber (Stein and Shurson, 2009; Table 5). The apparent total tract digestibility of dietary fiber averages 43.7%, but ranges from 23 to 55%. This variation in fiber digestibility is believed to influence digestibility of energy in DDGS. Apparent ileal digestibility and total tract digestibility of dietary fiber in DDGS is higher than in corn, and are presumed to be improved as a result of the processing and fermentation processes used in ethanol plants (Urriola et al., 2010). However, less than 50% of total dietary fiber is fermented over the entire digestive tract, indicating that more than 50% passes through pigs without being fermented (Urriola et al., 2010). As a result, there is a significant amount of non-fermented carbohydrate in DDGS that could potentially utilized to a greater extent if appropriate exogenous enzymes can be developed to enhance the utilization of these substrates in DDGS diets.

Table 5. Concentration of carbohydrates and apparent total tract digestibility (ATTD) of dietary fiber in corn distillers dried grains with solubles.[1,2]

Item	Average	Low value	High value	SD
Starch, total, %	7.3	3.8	11.4	1.4
Starch, soluble, %	2.6	0.5	5.0	1.2
Starch, insoluble, %	4.7	2.0	7.6	1.5
ADF, %	9.9	7.2	17.3	1.2
NDF, %	25.3	20.1	32.9	4.8
Insoluble TDF, %	35.3	26.4	38.8	4.0
Soluble TDF, %	6.0	2.36	8.54	2.1
TDF, %	42.1	31.2	46.3	4.9
ATTD of TDF, %	43.7	23.4	55.0	10.2

[1] N = 46 for data on starch, ADF, and NDF; n = 8 for data on insoluble, soluble, and total dietary fiber.
[2] Stein and Shurson, 2009.

In a recent collaborative research project between the Agricultural Research Service and the University of Minnesota, we evaluated the ME concentration of a variety of corn milling co-products (Anderson, 2009). Although one of the best fit equations included TDF in the prediction equation, [ME, kcal/kg DM = -1358 + (1.26 × GE) – (30.91 × TDF) – (33.14 × crude fat) (R^2 = 0.85, SE = 273)], the replacement of TDF with NDF had little impact on the overall equation: [ME, kcal/kg DM = -2161 + (1.39 × GE) – (20.70 × NDF) – (49.30 × crude fat) (R^2 = 0.77, SE = 337)], implying that for "corn fiber" there are low concentrations of pectans, gums, β-glucans, or fructan polysaccharides (as shown by the difference between TDF and NDF in Fig. 1). This can also be observed by comparing the relatively similar TDF and NDF concentrations in these co-products (Table 6). Furthermore, corn "fiber" has a large hemicellulose component as defined by the difference between NDF and ADF.

Table 6. Analyzed composition of corn co-products, DM basis[1]

Item	DDGS (WI)	DDGS (IA)	DDGS (SD)	RO-DDGS (SD)	DDGS (BPX)	Drum-DDGS (MN)	Microwave-DDGS (MN)	Dried solubles	Gluten feed
Crude protein	29.62	29.65	31.94	34.74	29.49	32.69	34.12	23.75	24.29
Starch	7.85	3.47	6.24	3.04	4.94	2.12	1.05	6.34	12.57
Crude fiber	7.05	7.76	7.56	8.69	7.95	7.93	8.35	0.08	8.56
TDF	30.34	38.14	35.69	37.20	35.90	35.38	43.18	16.07	40.07
NDF	34.61	40.13	40.12	50.96	33.41	44.87	49.12	2.33	42.66
ADF	11.25	10.55	14.42	15.82	8.62	13.16	14.66	0.49	9.90
Cellulose	10.64	10.12	11.72	12.72	8.21	11.95	13.37	0.79	9.17
Lignin	1.21	1.06	3.16	3.49	1.00	1.72	1.92	0.31	1.05

Item	DHDG corn	Dehy corn germ	Corn germ meal	Bran	Bran + solubles	Gluten meal	HP-DDG (MOR)	HP-DDG (Poet)	HP-DDG (ICM)
Starch	87.96	25.00	15.29	23.25	25.73	11.08	0.51	7.30	5.10
Crude fiber	0.60	4.87	10.69	11.54	4.80	1.44	8.14	9.42	7.87
TDF	2.61	24.78	47.76	53.60	26.65	9.24	28.80	31.28	36.75
NDF	4.27	27.37	61.05	56.86	25.21	12.25	43.52	32.00	51.09
ADF	0.49	6.13	12.49	13.14	5.35	7.57	25.42	12.61	15.11
Cellulose	0.77	5.21	11.71	12.78	5.38	5.95	22.55	12.05	14.25
Lignin	0.33	1.28	1.22	0.89	0.55	2.24	3.40	0.95	1.44

[1]Abbreviations: TDF, total dietary fiber; NDF, neutral detergent fiber; ADF, acid detergent fiber; DDGS, distillers dried grains with solubles; RO-DDGS, reduced oil-DDGS; drum- or microwave-dried DDGS; DHDG, dehulled-degermed; HP-DDG, high protein dried distillers grains. Abbreviations within brackets ( ) refers to the state or company where the product was obtained.

These results are similar to those reported by Leathers (1998), where the corn fiber composition from six studies representing different geographic regions showed that hemicellulose is the predominant constituent in corn fiber, followed by xylose (Table 7).

Table 7. Major components of corn fiber.

	Geographic location					
Component	A	B	C	D	E	F
Starch	22	11	18	22	20	23
Hemicellulose	40	53	32	47	29	39
Xylose	24	25	20	28	18	19
Arabinose	16	18	10	19	11	11
Cellulose	12	18	24	ND	14	ND
Protein	12	11	ND	ND	11	12

Consequently, when evaluating the effectiveness of exogenous enzymes, the composition of "fiber" must be considered in order for energy and nutrient digestibility to potentially be improved. This is clearly demonstrated by Li et al., (1996) who evaluated the effectiveness of adding β-glucanase to a broad range of diets, differing largely in β-glucan content. Their data showed that supplementation of β-glucanase had no effect on energy digestibility in wheat-, corn-, or rye-soybean meal diets, but did improve energy digestibility in barley-soybean meal diets (Table 8), which reflected the dietary differences in β-glucan concentrations.

Table 8. Effect of β-glucanase supplementation on energy digestibility.

	Diet composition, %			β-glucanase supplementation, %			
Diet	NDF	ADF	β-glucans	0	0.05	0.10	0.20
Barley-SBM	8.4	2.3	3.2	85.2[b]	87.8[ab]	86.4[ab]	88.5[a]
Wheat-SBM	7.9	2.5	0.8	86.8	88.1	88.4	88.4
Corn-SBM	8.1	1.9	0.3	85.8	84.4	83.8	85.7
Rye-SBM	7.4	2.1	0.7	87.2	88.0	88.1	87.1

EFFECTIVENESS OF COMMERCIAL ENZYME/ADDITIVE PRODUCTS IN NURSERY AND FINISHING DIETS CONTAINING DDGS ON NUTRIENT DIGESTIBILITY AND GROWTH PERFORMANCE[1]

MATERIALS AND METHODS

The experiment was approved by the Iowa State University Animal Care and Use Committee. Feed additives (Table 9) were selected based on their potential to affect energy and fiber digestion, or their ability to modulate the bacterial ecology within the gastrointestinal tract. The basal diets (Table 10) were formulated to be adequate in all nutrients relative to the NRC (1998) recommendation for each specific pig weight category over the 5 wk period, and included 30% dried distillers grains with solubles (DDGS) during each phase of growth. Titanium dioxide was added as an indigestible marker at 0.5% of the diet to determine apparent "nutrient" digestibility by the indirect method: $[1 - ((Ti_{feed} \times Nutrient_{feces})/(Ti_{feces} \times Nutrient_{feed})) \times 100]$. Feed additives were added at the manufacturers recommended rates to each diet. For all additives evaluated in this study, it was assumed that they contained the active ingredients and the level of activity listed on the product label (Table 9).

In the nursery experiment, a total of 192 pigs were used representing 3 groups of 64 pigs (11.9 kg average initial BW). Each group of pigs were randomly allotted to 2 rooms (32 pens/room) and subsequently placed into individual stainless steel pens measuring 0.46 m × 1.22 m. Pigs were individually fed their respective experimental diets over a 5 week feeding period. In the finisher experiment, a total of 96 pigs were used consisting of 2 groups of 48 pigs (98.4 kg average initial BW), which were randomly allotted to 2 rooms (24 pens/room), and subsequently placed into individual galvanized pens measuring 0.57 × 2.21 m. Pigs were individually fed their experimental diets over the 5 week feeding period. In each experiment, pigs were allowed *ad libitum* access to feed and water, and each room was maintained with 24-h lighting, was mechanically ventilated, and had a pull-plug manure storage system. Dietary treatments were randomly assigned to pens, with gender and BW maintained as equal as possible within and between groups. Experimental diets were fed in meal form. Fecal samples were collected at the end of week-1, week-3, and week-5 by collecting freshly voided feces into individual plastic bags and immediately storing samples at 0˚C until the end of the trial.

At the end of the trial, diets and feces were dried in a 70˚C forced air oven, weighed, 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 fiber was analyzed by method # 8 and #9, respectively, using filter-bag technology (Ankom2000,

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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 1N HCl followed by ICP spectrometry (Optima 5300DV, PerkinElmer, Shelton, CT).

Data were subjected to ANOVA (Proc GLM, SAS Inst. Inc., Cary, NC) with group, room, gender, week, and diet included in the model. There were no week × diet interactions, therefore, only the main effects of diet and week are presented, with means are reported as LSMEANS. In addition, only the pre-planned comparison between pigs fed each feed additive and pigs fed the diet containing no additive are presented. The pig was considered the experimental unit in each experiment.

Table 9. Characterization of exogenous feed additives.

Trade name	Manufacture	Lot # Date	Activity identification	Stated activity
Allzyme SSF	Alltech, Lexington, KY	215612/460369 2/2/2008	Not provided (NP)	NP
Bactocell	Lallemand Animal Nutrition, Milwaukee, WI	8022202 3/3/2008	Pediococcus acidilactici	10×10^9 CFU/g
BioPlus 2B	Chr. Hansen, Milwaukee, WI	2821721 1/31/2008	Bacillus licheniformis and Bacillus subtilus	2.2×10^9 CFU/g
Econase XT25	AB Enzymes, Darmstadt, Germany	7855 12/19/2007	Endo-1,4-β-xylanase	160,000 U/g
Hemicel	ChemGen Corp., Gaithersburg, MD	NP NP	Hemicellulase	1.4×10^6 U/g
Porzyme 9302	Danisco Animal Nutrition, Marlborough, UK	4320849505 8/11/2008	Xylanase	8,000 U/g
Releez-a-zyme 4M	Prince Agri Products Inc., Quincy, IL	31-2047 5/6/2008	β-glucanase Protease	440 U/g 11 U/g
Rovabio AP10%	Adisseo, Antony, France	NP NP	Endo-1,4-β-xylanase Endo-1,3(4)- β-glucanase	2,200 U/g 200 U/g
Roxazyme G2 G	DSM Nutritional Products Inc., Parsippany, NJ	NP NP	Endo-1,4-β-glucanase Endo-1,3(4)- β-glucanase Endo-1,4-β-xylanase	8,000 U/g 18,000 U/g 26,000 U/g
XPC yeast	Diamond V Mills Inc., Cedar Rapids, IA	300308 NP	*Saccharomyces cerevisiae* yeast culture	NP

Table 10. Composition of experimental diets, as-is basis.

Ingredient	Starter	Finisher
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 (21%P)	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	100.00	100.00

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

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

[3]Tylosin premix.

RESULTS AND DISCUSSION

Starter

In the starter experiment, most nutrient digestibility coefficients were unaffected by the addition of enzymes, yeast, or microbial cultures (Table 11). At the time of writing this manuscript, determinations of P digestibility were not completed. Nitrogen and S digestibility were improved by Roxazyme addition, but other nutrients were unaffected. In a similar manner, Rovabio and BactoCel both improved S digestibility, but all other nutrients were unaffected by their addition. It is unclear what, if any, value improved S digestibility may provide in these diets. In contrast, Porzyme and Hemicel decreased NDF digestibility, but did not affect other nutrient digestibility coefficients. This was an unexpected result since the product labels for these additives indicated the presence of enzymes that should be effective for improving digestibility of corn fiber. Supplementation of Econase, Allzyme, and Releezyme decreased the digestibility of various nutrients. However, regardless of positive or negative impact that enzymes, yeast, or microbial cultures had on the digestibility of various nutrients, there was no

impact on pig performance (Table 13). Digestibility of GE, N, C, S, ADF, NDF and ether extract increased from week-1 to week-5 ($P < 0.01$). These results suggest that the gastrointestinal tract of the 12 kg pig adapts to dietary fiber from DDGS and nutrient digestibility improves with continuous feeding over time. This finding is consistent with the increased ability of the digestive system in growing pigs to digest nutrients (especially fiber) with increasing age.

Finisher

In the finisher experiment, little impact of enzymes, yeast, or microbial cultures were noted on most nutrient digestibility coefficients (Table 12). Improvements in digestibilities were noted for the addition of Roxazyme (ether extract), Allzyme (ADF and NDF), and BioPlus2B (ADF), but the digestibilities of all other nutrients were unaffected. However, the improvement in fiber digestibility from adding Allzyme and BioPlus2B did not result in improved gross energy digestibility. Supplementation of Porzyme, Hemicel, Releezyme, XPC yeast and BactoCel exhibited negative impacts on digestibility of various nutrients. Unlike the nutrient digestibility responses observed for starter pigs, nutrient digestibility did not improve from week-1 to week-5. At the time of writing this manuscript, determinations of P digestibility were not completed. Similar to the results of the starter trial, there was no impact of enzymes, yeast, or microbial cultures on pig performance (Table 14).

Many of the enzyme/additive products evaluated in this study contained ingredients that should have been effective in for improving energy/fiber digestibility in 30% DDGS diets. Since we did not confirm the specified enzyme/active ingredient activity for these additives, it may be possible that they did not contain enough activity to provide significant improvements in digestibility for many of the nutrients evaluated. Another possible reason for the lack of growth performance and notable nutrient digestibility responses may have been due to the source of 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 DDGS sources. Perhaps the 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. Finally, since these diets were formulated to meet the nutrient needs of pigs in each growth phase evaluated, the improvements or decreases in nutrient digestibility that did occur were too small to influence overall pig performance.

Table 11. Apparent nutrient digestibility (%) of starter pigs fed exogenous feed additives.[1]

Treatment[2]	GE	N	C	S	P	ADF	NDF	EE
Control	79.2	79.9	79.9	78.5	NA	40.1	36.6	64.2
Roxazyme	79.6	81.1	80.3	79.9	NA	38.8	39.1	63.3
P value[3]	*0.40*	*0.10*	*0.42*	*0.06*	NA	*0.58*	*0.16*	*0.61*
Porzyme	79.0	79.4	79.7	78.8	NA	36.3	33.2	64.9
P value[3]	*0.67*	*0.47*	*0.61*	*0.66*	NA	*0.13*	*0.07*	*0.67*
Econase	78.3	78.7	79.1	77.0	NA	35.6	32.5	62.8
P value[3]	*0.07*	*0.07*	*0.10*	*0.04*	NA	*0.06*	*0.03*	*0.45*
Rovabio	80.0	80.7	80.7	79.9	NA	38.1	36.5	64.4
P value[3]	*0.12*	*0.25*	*0.14*	*0.06*	NA	*0.39*	*0.97*	*0.88*
Hemicel	78.9	79.0	79.6	79.0	NA	36.3	33.4	65.5
P value[3]	*0.53*	*0.17*	*0.48*	*0.49*	NA	*0.12*	*0.09*	*0.45*
Allzyme	76.5	77.6	77.4	77.5	NA	30.6	27.3	61.5
P value[3]	*0.01*	*0.01*	*0.01*	*0.17*	NA	*0.01*	*0.01*	*0.14*
Releezyme	76.9	77.4	77.7	77.3	NA	30.0	29.9	61.1
P value[3]	*0.01*	*0.01*	*0.01*	*0.09*	NA	*0.01*	*0.01*	*0.08*
XVC yeast	79.6	80.1	80.3	79.4	NA	39.0	36.4	65.9
P value[3]	*0.40*	*0.81*	*0.46*	*0.26*	NA	*0.63*	*0.95*	*0.33*
BactoCel	80.0	80.4	80.3	80.1	NA	39.4	39.3	64.9
P value[3]	*0.14*	*0.55*	*0.42*	*0.03*	NA	*0.76*	*0.15*	*0.66*
BioPlus2B	79.5	80.3	80.0	79.6	NA	37.7	35.0	65.0
P value[3]	*0.59*	*0.64*	*0.85*	*0.17*	NA	*0.31*	*0.39*	*0.64*
P value[4]	*0.01*	*0.01*	*0.01*	*0.01*	NA	*0.01*	*0.01*	*0.08*
SE[4]	0.35	0.48	0.34	0.52	NA	1.714	1.318	1.221
Wk-1[5]	76.9	76.0	77.6	75.4	NA	31.4	28.5	70.6
Wk-3	79.2	80.1	79.8	79.3	NA	36.2	35.8	61.9
Wk-5	80.5	82.4	81.2	81.8	NA	42.0	39.1	59.4
P value[6]	*0.01*	*0.01*	*0.01*	*0.01*	NA	*0.01*	*0.01*	*0.01*
SE[6]	0.18	0.25	0.18	0.27	NA	0.93	0.69	0.64

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

[2] Roxazyme G2, 200 g/T (DSM Nutritional Products Inc., Parsippany, NJ); Porzyme 9302, 227 g/T (Danisco Animal Nutrition, Marlborough, UK); Econase XT25, 136 g/T (AB Enzymes, Darmstadt, Germany); Rovabio AP10, 454 g/T (Adisseo, Antony, France); Hemicel, 454 g/T (ChemGen Corp., Gaithersburg, MD); Allzyme SSF, 454 g/T (Alltech, Lexington, KY); Release, 454 g/T (Prince Agri Products Inc., Quincy, IL); XPC Yeast, 1,816 g/T (Diamond V Mills Inc., Cedar Rapids, IA); BactoCel, 100 g/T (Lallemand Animal Nutrition, Milwaukee, WI); BioPlus 2B, 454 g/t (Chr. Hansen, Milwaukee, WI).

[3] 'P value' represents comparison of the feed additive to the control diet.

[4] Model P 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 and SE value for week.

Table 12. Apparent nutrient digestibility (%) of finisher pigs fed exogenous feed additives.[1]

Treatment[2]	GE	N	C	S	P	ADF	NDF	EE
Control	81.4	83.8	82.3	82.7	NA	52.9	42.1	46.5
Roxazyme	80.9	81.9	81.7	81.9	NA	49.8	38.1	49.9
P value[3]	*0.45*	*0.12*	*0.35*	*0.27*	NA	*0.15*	*0.14*	*0.08*
Porzyme	79.4	80.9	80.4	80.1	NA	43.8	34.0	44.4
P value[3]	*0.01*	*0.01*	*0.01*	*0.01*	NA	*0.01*	*0.01*	*0.28*
Econase	80.8	82.7	81.8	83.1	NA	50.8	42.0	46.7
P value[3]	*0.40*	*0.15*	*0.45*	*0.55*	NA	*0.33*	*0.95*	*0.82*
Rovabio	81.3	83.7	82.3	82.8	NA	52.7	43.5	45.5
P value[3]	*0.98*	*0.92*	*0.96*	*0.88*	NA	*0.93*	*0.62*	*0.62*
Hemicel	80.7	82.8	81.6	82.4	NA	48.3	37.4	44.3
P value[3]	*0.30*	*0.20*	*0.27*	*0.74*	NA	*0.03*	*0.08*	*0.25*
Allzyme	82.1	84.2	83.00	83.3	NA	56.6	46.9	48.1
P value[3]	*0.27*	*0.61*	*0.29*	*0.38*	NA	*0.08*	*0.08*	*0.41*
Releezyme	79.5	80.7	80.4	79.9	NA	50.0	35.4	38.1
P value[3]	*0.01*	*0.01*	*0.01*	*0.01*	NA	*0.18*	*0.02*	*0.01*
XVC yeast	80.1	82.5	81.1	82.1	NA	50.1	38.4	43.1
P value[3]	*0.05*	*0.10*	*0.05*	*0.36*	NA	*0.19*	*0.18*	*0.08*
BactoCel	80.8	82.3	82.0	82.4	NA	50.1	39.5	49.6
P value[3]	*0.40*	*0.05*	*0.57*	*0.73*	NA	*0.19*	*0.34*	*0.11*
BioPlus2B	81.7	83.2	82.7	82.6	NA	56.3	45.4	38.6
P value[3]	*0.58*	*0.46*	*0.49*	*0.91*	NA	*0.10*	*0.23*	*0.01*
P value[4]	*0.01*	*0.01*	*0.01*	*0.01*	NA	*0.01*	*0.01*	*0.01*
SE[4]	0.45	0.55	0.45	0.47	NA	1.50	1.95	1.38
Wk-1[5]	80.6	82.3	81.5	81.7	NA	50.7	40.1	45.3
Wk-3	80.8	82.5	81.8	82.3	NA	51.7	40.5	44.9
Wk-5	81.0	83.0	82.0	82.3	NA	50.8	40.2	44.8
P value[6]	*0.43*	*0.17*	*0.39*	*0.17*	NA	*0.62*	*0.96*	*0.89*
SE[6]	0.24	0.30	0.24	0.25	NA	0.80	1.04	0.73

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

[2] Roxazyme G2, 200 g/T (DSM Nutritional Products Inc., Parsippany, NJ); Porzyme 9302, 227 g/T (Danisco Animal Nutrition, Marlborough, UK); Econase XT25, 136 g/T (AB Enzymes, Darmstadt, Germany); Rovabio AP10, 454 g/T (Adisseo, Antony, France); Hemicel, 454 g/T (ChemGen Corp., Gaithersburg, MD); Allzyme SSF, 454 g/T (Alltech, Lexington, KY); Release, 454 g/T (Prince Agri Products Inc., Quincy, IL); XPC Yeast, 908 g/T (Diamond V Mills Inc., Cedar Rapids, IA); BactoCel, 100 g/T (Lallemand Animal Nutrition, Milwaukee, WI); BioPlus 2B, 454 g/t (Chr. Hansen, Milwaukee, WI).

[3] 'P value' represents comparison of the feed additive to the control diet.

[4] Model P 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 and SE value for week.

Table 13. Performance of pigs fed exogenous feed additives.[1]

	Starter, 12 – 33 kg BW			Finisher, 98 – 132 kg BW		
Treatment[2]	ADG, kg	ADFI, kg	G:F	ADG, kg	ADFI, kg	G:F
Control	0.640	1.126	0.572	0.999	3.032	0.333
Roxazyme	0.638	1.100	0.583	0.975	3.084	0.321
Porzyme	0.642	1.131	0.570	0.979	3.077	0.318
Econase	0.653	1.133	0.578	1.051	3.240	0.325
Rovabio	0.648	1.148	0.565	0.906	2.985	0.302
Hemicel	0.629	1.149	0.551	0.933	3.239	0.292
Allzyme	0.651	1.140	0.574	0.961	3.118	0.311
Releezyme	0.639	1.109	0.579	0.983	3.115	0.311
XVC yeast	0.653	1.157	0.568	0.862	2.930	0.294
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
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 16-18 and 8 individually fed pigs per treatment in the starter and finisher phase, respectively.

[2] Roxazyme G2, 200 g/T (DSM Nutritional Products Inc., Parsippany, NJ); Porzyme 9302, 227 g/T (Danisco Animal Nutrition, Marlborough, UK); Econase XT25, 136 g/T (AB Enzymes, Darmstadt, Germany); Rovabio AP10, 454 g/T (Adisseo, Antony, France); Hemicel, 454 g/T (ChemGen Corp., Gaithersburg, MD); Allzyme SSF, 454 g/T (Alltech, Lexington, KY); Release, 454 g/T (Prince Agri Products Inc., Quincy, IL); XVC Yeast, 1,816 g/T starter or 908 g/T finisher (Diamond V Mills Inc., Cedar Rapids, IA); BactoCel, 100 g/T (Lallemand Animal Nutrition, Milwaukee, WI); BioPlus 2B, 454 g/t (Chr. Hansen, Milwaukee, WI).

CONCLUSIONS

Application of enzymes in an effort to improve nutrient digestibility of plant-based feed ingredients for swine and poultry has been studied for decades. However, with a large diversity and concentration of chemical characteristics existing among plant-based feed ingredients, improvements in nutrient digestibility and pig performance from adding exogenous enzymes to growing pig diets depends on understanding these characteristics in relation to enzyme activity. Essentially, the enzyme must match the target substrate(s), there may need to be a 'cocktail' of enzymes to effectively breakdown the complex matrixes of fibrous carbohydrate structures, and there must be some negative role that these substrates have on nutrient digestibility or voluntary feed intake. With the inverse relationship between fiber content and energy digestibility being well described for several feed ingredients, it is only logical that development of enzymes that degrade fiber, and thereby improve energy digestibility or voluntary feed intake will have a high chance to be beneficial, both metabolically and economically. The results of our study suggest that some of the enzyme/additive products evaluated had variable, but small effects on nutrient digestibility, but none of these products were effective in improving starter and finishing pig growth performance when fed nutritionally adequate corn-soy diets containing 30% DDGS.

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