Effects of drought-affected corn and nonstarch polysaccharide enzyme inclusion on nursery pig growth performance\textsuperscript{1,2}

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ABSTRACT: The effectiveness of carbohydrase enzymes has been inconsistent in corn-based swine diets; however, the increased substrate of nonstarch polysaccharides in drought-affected corn may provide an economic model for enzyme inclusion, but this has not been evaluated. A total of 360 barrows (PIC 1050 × 337, initially 5.85 kg BW) were used to determine the effects of drought-affected corn inclusion with or without supplementation of commercial carbohydrases on growth performance and nutrient digestibility of nursery pigs. Initially, 34 corn samples were collected to find representatives of normal and drought-affected corn. The lot selected to represent the normal corn had a test weight of 719.4 kg/m\textsuperscript{3}, 15.0% moisture, and 4.2% xylan. The lot selected to represent drought-affected corn had a test weight of 698.8 kg/m\textsuperscript{3}, 14.3% moisture, and 4.7% xylan. After a 10-d acclimation period postweaning, nursery pigs were randomly allotted to 1 of 8 dietary treatments in a completely randomized design. Treatments were arranged in a 2 × 4 factorial with main effects of corn (normal vs. drought affected) and enzyme inclusion (none vs. 100 mg/kg Enzyme A vs. 250 mg/kg Enzyme B vs. 100 mg/kg Enzyme A + 250 mg/kg Enzyme B). Both enzymes were included blends of β-glucanase, cellulose, and xylanase (Enzyme A) or hemicellulase and pectinases (Enzyme B). Pigs were fed treatment diets from d 10 to 35 postweaning in 2 phases. Feed and fecal samples were collected on d 30 postweaning to determine apparent total tract digestibility of nutrients. The nutrient concentrations of normal and drought-affected corn were similar, which resulted in few treatment or main effects differences of corn type or enzyme inclusion. No interactions were observed (\(P > 0.10\)) between corn source and enzyme inclusion. Overall (d 10 to 35), treatments had no effect on ADG or ADFI, but enzyme A inclusion tended to improve (\(P < 0.10; 0.74\) vs. 0.69) G:F, which was primarily driven by the improved feed efficiency (0.76 vs. 0.72; \(P < 0.05\)) of pigs fed Enzyme A in Phase 2 (d 10 to 25 postweaning) and was likely a result of improved xylan utilization. In conclusion, drought stress did not alter the nonstarch polysaccharide concentration of corn beyond xylan concentration, so it was not surprising that enzyme inclusion showed little benefit to nursery pig growth performance. However, improved feed efficiency of pigs fed diets containing Enzyme A from d 10 to 25 postweaning warrants further investigation.

Key words: carbohydrase, corn, drought, enzyme, growth, pig

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INTRODUCTION

Drought conditions are known to reduce cereal grain yields, lower energy density, and affect animal growth performance. During severe drought, cereal grains generally have fewer and smaller kernels due to reduced endosperm accretion (Zinselmeier et al., 1999). Kernel number is the leading factor
influencing yield, whereas kernel size is more likely to influence test weight (Andrade et al., 2002). Kernel number is determined by pollination (Andrade et al., 2002). If drought stress occurs shortly after pollination, embryos form but are then aborted, greatly reducing kernel number and, subsequently, crop yield (Zinselmeier et al., 1999). Meanwhile, drought conditions during kernel development lead to light kernel weights (Çakir, 2004). Moisture restriction reduces endosperm production, thus potentially altering the endosperm:pericarp ratio. Because the pericarp portion of cereal grains is high in fiber, this ratio alteration may change the nutrient composition of the individual kernel to be higher in fiber components, such as nonstarch polysaccharides.

Carbohydrase enzymes may increase the nutrient availability of carbohydrates bound in nonstarch polysaccharide fractions (Jones et al., 2010). Commercially available carbohydrase enzymes have been developed and are most effective in diets that contain ingredients with higher nonstarch polysaccharide concentrations than would be found in corn (Omogbenigun et al., 2004). The effectiveness of commercial carbohydrase enzymes has been inconsistent in corn–soybean meal–based swine diets; however, the increased substrate of nonstarch polysaccharides in drought-affected corn may provide an economic model for enzyme inclusion (Dänicke et al., 1999). The objective of this research was to determine the effects of drought-affected corn inclusion with or without supplementation of commercial carbohydrases on growth performance and nutrient digestibility of nursery pigs.

**MATERIALS AND METHODS**

The Kansas State University Institutional Animal Care and Use Committee approved the protocols used in this experiment. The study was conducted at the Kansas State University Segregated Early Weaning Facility in Manhattan.

**Grain Composition and Diet Manufacturing**

Initially, 34 corn samples were collected and analyzed to select 2 corn sources representing “normal” and “drought affected” for use in diet manufacturing. The corn selected to represent normal corn had a test weight of 719.4 kg/m³ and 15.0% moisture and contained 0.77% β-glucan, 4.2% xylan, 2.5% cellulose, and 7.8% hemicellulose (Table 1). The normal corn was grown in an area that received 83.5% of the average rainfall for the area and average soil moisture (30 cm; National Oceanic and Atmospheric Administration, 2012a). The corn selected to represent drought-affected corn had a

| Item                              | Normal corn | Drought-affected corn |
|-----------------------------------|-------------|-----------------------|
| Temperature                       |             |                       |
| Average actual temperature, °C    | 17.7        | 18.7                  |
| Difference from average temperature, °C | 2.0        | 0.9                   |
| Calculated percentage of average temperature, % | 94.8     | 97.5                  |
| Precipitation                     |             |                       |
| Total actual rainfall, cm         | 55.37       | 35.56                 |
| Difference from total normal rainfall, cm | -10.92  | -30.73                |
| Calculated percentage of total normal rainfall, % | 83.50    | 58.00                 |
| Average actual soil moisture, cm  | 29.97       | 20.06                 |
| Characteristics                   |             |                       |
| U.S. Grade                        | 2           | 2                     |
| Yield, t/ha                       | 8.79        | 5.46                  |
| Aflatoxin, mg/kg                  | <0.005      | 0.006                 |
| Test weight, kg/m³                | 719.4       | 698.8                 |
| Moisture, %                       | 15.0        | 14.3                  |
| Total damaged kernels, %          | 2.9         | 0.2                   |
| Broken corn and foreign material, % | 0.5       | 0.8                   |
| Ground corn geometric mean particle size | 404     | 403                   |
| Ground corn particle size standard deviation | 2.15   | 2.03                  |
| Analyzed nutrient composition, %  |             |                       |
| Moisture                          | 12.6        | 12.4                  |
| CP                                | 8.5         | 9.4                   |
| Crude fat                         | 3.2         | 3.2                   |
| Crude fiber                       | 1.4         | 1.5                   |
| Ash                               | 1.4         | 1.3                   |
| Starch                            | 64.3        | 65.7                  |
| ADF                               | 2.9         | 3.0                   |
| NDF                               | 10.6        | 10.6                  |
| Cellulose                         | 2.5         | 2.5                   |
| Xylan                             | 4.2         | 4.7                   |
| β-glucan                          | 0.77        | 0.83                  |
| Lignin                            | 0.38        | 0.48                  |
| Calculated nutrient composition, %|             |                       |
| Hemicellulose                     | 7.8         | 7.6                   |

1 Grown in Lewis, IA, and weather station reported in Atlantic, IA.
2 Grown in Harlan, IA, and weather station reported in Harlan, IA.
3 National Oceanic and Atmospheric Administration (2012a,b).
4 Determined by a licensed Grain Inspection, Packers and Stockyards Administration grain inspector with certified weights and instruments.
5 Analyzed according to AOAC International (AOAC, 2007) methods 991.31 (aflatoxin), 924.05 (DM), 981.13 (CP), 920.39 (crude fat), 978.10 (crude fiber), 973.18 (ADF), 973.18 (cellulose and lignin), and 995.16 (β-glucan).
6 Determined according to American Society of Agricultural Engineers (2003) standard S319.3.
7 Analyzed according to Holst (1973).
8 Analyzed according to Hudson et al. (1982).
9 Calculated using the equation NDF – ADF = hemicellulose.
test weight of 698.8 kg/m³, 14.3% moisture, and 0.83% β-glucan, 4.7% xylan, 2.5% cellulose, and 7.6% hemi-cellulose. The drought-affected corn was grown in an area that received 58.0% of average rainfall and had below-average soil moisture (7.9 in.; National Oceanic and Atmospheric Administration, 2012b). Both corn samples were yellow dent U.S. number 2 and graded according to the Official United States Standards for Grain by the Federal Grain Inspection Service.

Grains were ground in a hammer mill to a common particle size and similar SD and used to manufacture 2 phases of nursery pig diet. These were phase 2 and 3 of a 3-phase nursery feeding program; phase 1 was fed as a common diet during the acclimation period. Within phase, all diets were manufactured from the same formulation, with grain type given equal nutritive value and enzymes included in place of grain (Table 2). The 8 dietary treatments were fed in meal form and arranged in a 2 × 4 factorial with main effects of corn (normal vs. drought affected) and enzyme inclusion (none vs. 100 mg/kg Enzyme A vs. 250 mg/kg Enzyme B vs. 100 mg/kg Enzyme A + 250 mg/kg Enzyme B). Both enzymes were commercial non-starch polysaccharide enzymes that included blends of 70 units/kg complete feed β-glucanase; 80 units/kg complete feed cellulose and 270 units/kg complete feed xylanase (Enzyme A) or 50 fungal β-glucanase units/g complete feed and 250 units/g complete feed hemicellulose; and 3,000 units/g complete feed pectinase (Enzyme B). Enzyme A was Roxazyme G2G and Enzyme B was Ronozyme VP, both marketed by DSM Nutritional Products (Parsippany, NJ).

Diets included 0.4% titanium dioxide as an indigestible marker and were also analyzed for proximate analysis and carbohydrate composition (Table 3).

**Pigs and Housing**

A total of 360 barrows (PIC 1050 × 337, initially 5.85 kg and 21 d of age) were used in a 25-d growth and nutrient digestibility experiment. Pigs were allotted to pens at weaning (d 0) and were acclimated to a common phase 1 diet for 10 d. On d 10 after placement, pigs were weighed and pens of pigs were randomly allotted to 1 of 8 dietary treatments in a completely randomized design. There were 5 pigs per pen (1.5 by 1.5 m) and 9 pens per treatment. Pigs were provided unlimited access to feed and water through a 4-hole dry self-feeder and cup waterer. Treatments were fed in 2 phases: phase 2 from d 10 to 25 postweaning and phase 3 from d 25 to 35 postweaning. Pigs were weighed and feed disappearance was measured on d 10, 25, and 35 postweaning for calculation of ADG, ADFI, and G:F.

### Table 2. Calculated diet composition (as-fed basis)¹

| Ingredient, %       | Phase 2  | Phase 3  |
|---------------------|----------|----------|
| Corn                | 54.70    | 63.84    |
| Soybean meal, 46.5% CP | 27.15    | 30.40    |
| Fish meal           | 3.00     | 0.00     |
| Spray-dried whey    | 10.00    | 0.00     |
| Soy oil             | 2.00     | 2.00     |
| Monocalcium P, 21% P | 0.65     | 1.05     |
| Limestone           | 0.88     | 1.00     |
| Salt                | 0.35     | 0.35     |
| Vitamin premix²     | 0.25     | 0.25     |
| Trace mineral premix³ | 0.15     | 0.15     |
| Lysine HCl          | 0.23     | 0.31     |
| ni-Methionine       | 0.11     | 0.11     |
| l-Threonine         | 0.11     | 0.12     |
| Phytase             | 0.011    | 0.011    |
| Titanium dioxide    | 0.4      | 0.4      |

Calculated analyses

| Standardized ileal digestible (SID) AA, % | Phase 2 | Phase 3 |
|------------------------------------------|---------|---------|
| Lysine                                   | 1.25    | 1.20    |
| Isoleucine:lysine                        | 62      | 62      |
| Leucine:lysine                           | 129     | 131     |
| Methionine:lysine                        | 34      | 33      |
| Met and Cys:lysine                       | 58      | 58      |
| Threonine:lysine                         | 64      | 63      |
| Tryptophan:lysine                        | 17.5    | 17.5    |
| Valine:lysine                            | 69      | 69      |
| Total lysine, %                          | 1.38    | 1.33    |
| ME, kcal/kb                              | 3,411   | 3,410   |
| SID Lysine:ME, g/Mcal                    | 3.67    | 3.51    |
| CP, %                                    | 20.8    | 20      |
| Ca, %                                    | 0.8     | 0.7     |
| P, %                                     | 0.64    | 0.61    |
| Available P, %                           | 0.50    | 0.43    |

¹Each phase of treatment diets were manufactured from the same formulation, with grain type given equal nutritive value and enzymes included in place of corn. Enzyme addition was 100 mg/kg Enzyme A, 250 mg/kg Enzyme B, or 100 mg/kg Enzyme A + 250 mg/kg Enzyme B. Enzyme A was Roxazyme G2G and Enzyme B was Ronozyme VP, both marketed by DSM Nutritional Products (Parsippany, NJ). Treatments were fed in 2 phases: Phase 2 from d 10 to 25 postweaning and Phase 3 from d 25 to 35 postweaning.

²Provided per kilogram of diet: 11,023 IU vitamin A; 1,378 IU vitamin D₃; 4,4 IU vitamin E; 4 mg vitamin K; 8 mg riboflavin; 28 mg pantothenic acid; 50 mg niacin; and 0.04 mg vitamin B₁₂.

³Provided per kilogram of diet: 40 mg Mn from manganese oxide, 17 mg Fe from iron sulfate, 17 mg Zn from zinc sulfate, 2 mg Cu from copper sulfate, 0.30 mg I from calcium iodate, and 0.30 mg Se from sodium selenite.

### Sample Collection, Analyses, and Calculations

Feed samples were collected on d 15 (phase 2) and 30 (phase 3), and fecal grab samples were collected on d 30. Feed samples were pooled across multiple bags within treatment throughout each phase and fecal samples were collected on d 30 by rectal stimulation. Samples were stored at −20°C, oven-dried, ground through a 0.5-mm screen, and analyzed for DM, ash, CP, crude fat, crude fiber, and titanium concentration.
Percentage DM and ash were determined according to modified methods 930.15 and 942.05 (AOAC, 2007), respectively, in which samples were dried at 105 or 600°C, respectively, to a constant weight. Nitrogen content was determined by Kjeldahl according to method 981.13 (AOAC, 2007). Crude protein was expressed as N × 6.25. Crude fat was calculated by ether extraction after acid hydrolysis according to method 920.39 and crude fiber according to method 978.10 (AOAC, 2007). Total starch was calculated according to American Association of Cereal Chemists International method 76-13 (McCleary et al., 1997). Acid detergent fiber was determined according to method 973.18 (AOAC, 2007) and NDF was determined according to Holst (1973). Cellulose and lignin were determined according to method 973.18 and β-glucan was determined according to method 995.16 (AOAC, 2007). Xylan concentration was determined according to Hudson et al. (1982). Titanium was analyzed according to Leone (1973). All chemical analyses were performed in duplicate and repeated when intraduplicate CV exceeded 1%. Dry matter and apparent total tract digestibility of nutrients were calculated as explained by Lewis et al. (2015).

### Statistical Analysis

Data were analyzed using the GLIMMIX procedure of SAS 9.3 (SAS Inst. Inc., Cary, NC) with the main effects serving as fixed effects. There were no random effects. All interactions were insignificant ($P > 0.24$) and therefore removed from the model. Preplanned orthogonal contrasts included enzyme vs. no enzyme inclusion (regardless of enzyme type

### Table 3. Analyzed or directly calculated nutrient composition of nursery pig diets

| Item                        | Phase 2 analyzed composition, % | Phase 2 calculated composition, % | Phase 3 analyzed composition, % | Phase 3 calculated composition, % |
|-----------------------------|---------------------------------|-----------------------------------|---------------------------------|-----------------------------------|
|                             | Normal Drought                  | Normal Drought                    | Normal Drought                  | Normal Drought                    |
|                             | None A                           | None B                            | None A + B                      | None A + B                        |
|                             | CP 20.5 21.0                     | 22.7 22.5                         | 20.7 20.3                       | 20.3 20.0                         |
|                             | Moisture 9.9 9.7                 | 9.0 9.8                           | 9.7 9.4                         | 9.8 9.5                           |
|                             | Crude fat 3.4 4.4                | 3.8 3.6                           | 4.2 4.7                         | 4.6 4.3                           |
|                             | Crude fiber 1.9 2.0              | 2.2 2.2                           | 2.0 2.2                         | 1.9 2.2                           |
|                             | Ash 6.1 6.1                      | 6.2 5.8                           | 6.4 6.4                         | 5.7 6.3                           |
|                             | Starch 39.2 34.8                 | 37.3 41.1                         | 39.8 40.2                       | 37.4 37.0                         |
|                             | ADF 3.1 3.2                      | 3.2 3.2                           | 3.5 3.4                         | 3.5 3.7                           |
|                             | NDF 9.0 9.1                      | 9.0 9.1                           | 8.9 8.3                         | 9.7 9.5                           |
|                             | Cellulose 2.6 2.7                | 2.9 2.7                           | 3.0 2.9                         | 2.9 3.1                           |
|                             | Xylan 27.6 32.2                  | 27.8 32.0                         | 27.5 32.0                       | 27.6 32.1                         |
|                             | β-glucan 0.48 0.42               | 0.45 0.50                         | 0.49 0.49                       | 0.45 0.45                         |
|                             | Lignin 0.46 0.47                 | 0.38 0.51                         | 0.54 0.51                       | 0.64 0.65                         |
|                             | Hemicellulose² 5.9 5.9           | 5.8 5.9                           | 5.4 4.9                         | 6.2 5.7                           |
|                             | Starch 40.2 43.3                 | 45.4 47.2                         | 46.9 45.8                       | 46.4 41.4                         |
|                             | ADF 3.6 3.7                      | 3.4 3.7                           | 3.2 3.8                         | 3.4 3.8                           |
|                             | NDF 9.8 9.8                      | 9.3 10.3                          | 10.0 10.8                       | 9.8 9.3                           |
|                             | Cellulose 3.3 3.3                | 3.2 3.4                           | 2.9 3.5                         | 3.2 3.5                           |
|                             | Xylan 30.4 35.0                  | 30.5 35.4                         | 30.8 35.5                       | 30.3 35.2                         |
|                             | β-glucan 0.49 0.53               | 0.55 0.58                         | 0.57 0.56                       | 0.57 0.50                         |
|                             | Lignin 0.35 0.42                 | 0.17 0.29                         | 0.31 0.31                       | 0.29 0.28                         |
|                             | Hemicellulose² 6.2 6.1           | 5.9 6.5                           | 6.8 7.1                         | 6.4 5.5                           |

1. Enzyme A was Roxazyme G2G and Enzyme B was Ronozyme VP, both marketed by DSM Nutritional Products (Parsippany, NJ).
2. Calculated using the equation NDF – ADF = hemicellulose.
or corn type), Enzyme A inclusion vs. no enzyme inclusion (regardless of corn type), Enzyme B inclusion vs. no enzyme inclusion (regardless of corn type), and Enzyme A + B inclusion vs. no enzyme inclusion (regardless of corn type). Results were considered significant if \( P < 0.05 \) and trends if \( 0.05 < P < 0.10 \).

**RESULTS AND DISCUSSION**

Phase 2 nutrient concentrations for total starch among the 8 dietary treatments ranged from 34.8 to 41.1%, cellulose ranged from 2.6 to 3.1%, xylan ranged from 27.5 to 32.2%, and β-glucan ranged from 0.42 to 0.50%. Xylan concentration was numerically greater in diets containing drought-affected corn, which was expected given that normal corn had a xylan concentration of 4.2% compared to 4.7% xylan concentration in drought-affected corn. Bach Knudsen (1997) reported that corn and soybean would have an expected xylan concentration of 42 and 17 g/kg, respectively, which is similar to our values for normal corn. No other patterns were apparent when comparing diets manufactured from normal vs. drought-affected corn. Phase 3 nutrient concentrations for total starch among the 8 dietary treatments ranged from 40.2 to 46.9%, cellulose ranged from 2.9 to 3.5%, xylan ranged from 30.4 to 35.5%, and β-glucan ranged from 0.49 to 0.58%. Again, no patterns were apparent when comparing diets manufactured from normal vs. drought-affected corn except for the differences in xylan concentration. The similarities in carbohydrate analyses between the normal and drought-affected corn sources were surprising, particularly considering the extreme differences in yield between the drought-affected and normal corn sources. Although some nutrients from drought-affected corn were altered, most notably CP and starch, other nutrient concentrations representing the nonstarch polysaccharide fraction remained largely unaffected. The combined knowledge of yield and average soil moisture concentrations confirms that the drought-affected corn source was subjected to water stress. Drought stress that occurs during fertilization can lead to embryo abortion, thus reducing kernel number (Çakir, 2004; Grant et al., 1989). However, similarities in nutrient composition suggest that water stress occurred before or during silking, thus affecting yield by decreasing kernel number and not necessarily kernel development. Water stress during the kernel development phase may have been insufficient to interfere with endosperm accretion or affect the endosperm:pericarp ratio. The similarities in nonstarch polysaccharide concentrations between the 2 corn sources also led to similar concentrations across all 8 dietary treatments.

Corn type (normal vs. drought affected) did not affect final BW, ADG, ADFI, or G:F in either phase or overall \( P > 0.10 \); Table 4). Similarly, corn type did not affect the apparent total tract digestibility of DM, ash, CP, or crude fat \( P > 0.10 \), but pigs fed diets manufactured from normal corn had greater \( P < 0.05 \) apparent total tract digestibility of crude fiber than those fed diets manufactured from drought-affected corn, which may be attributed to greater xylan concentration in drought-affected corn.

Because there appeared to be few other differences in nonstarch polysaccharide substrates among corn types or diets, it was not surprising that enzyme inclusion did not affect pig final BW, ADG, or ADFI \( P > 0.10 \). Enzyme inclusion did not affect \( P > 0.10 \) G:F from d 10 to 25 or d 25 to 35 but tended to affect \( P < 0.10 \) G:F overall, with the greatest feed efficiency in pigs fed diets with Enzyme A. Enzyme inclusion did not affect the apparent total tract digestibility of DM, crude fat, or crude fiber \( P > 0.10 \), but it affected the apparent total tract digestibility of ash \( P < 0.05 \). Nonstarch polysaccharides are known to affect mineral digestibility in vitro, and hemicelullose in particular has been shown to bind to essential minerals, such as calcium, magnesium, and manganese (Mod et al., 1982). However, others argue that nonstarch polysaccharides have a minimal effect on mineral utilization in swine (Kornegay and Moore, 1986; Kerr and Shurson, 2013). Interestingly, the increase in ash digestibility was driven by the inclusion of Enzyme A, where its inclusion alone or in combination with Enzyme B increased ash digestibility compared to diets without enzyme \( P > 0.05 \). Meanwhile, supplementing diets with Enzyme B, which contained hemicellulase, resulted in similar ash digestibility as those diets without enzyme inclusion \( P > 0.10 \). One would expect that enzyme inclusion would lead to improved N digestibility because nonstarch polysaccharides increase endogenous N secretion and therefore excretion of bacterial N (Borel et al., 1989; Kerr and Shurson, 2013). However, Enzyme B supplementation tended to unexplainably decrease CP digestibility compared to diets without enzyme \( P < 0.10 \). Still, because effects of enzyme inclusion were not observed in growth performance, the consequences of these findings are indeterminate.

Preplanned orthogonal contrasts revealed few effects. The only growth performance effects were that inclusion of Enzyme A tended to improve \( P < 0.10 \) overall ADG and significantly improved \( P < 0.05 \) G:F from d 10 to 25 compared with no enzyme inclusion. Potentially, this may be attributed to improved utilization of xylan within the diet, because xylanase was included in Enzyme A but not in Enzyme B. Others have observed improvements in growth performance and nutrient digestibility when pigs were fed corn–soybean meal–based diets with enzyme blends.
that included xylanase (Fang et al., 2007; Yi et al., 2013). Including either Enzyme A or Enzyme B alone improved (P < 0.05) apparent total tract digestibility of ash compared with no enzyme inclusion, but no other digestibility effects were observed and there were no effects of the enzymes in combination (P > 0.10).

The mode of action of carbohydrase enzymes is not well known and is inconsistent (Bedford, 2000). Carbohydrase enzymes seem to be most effective in swine diets formulated with higher fiber ingredients, such as wheat distillers dried grains with solubles, barley, rye, or wheat (Omogbenigun et al., 2004; Emiola, 2009). The multienzymes seem less effective when included in diets based on corn and soybean meal or even with corn distillers dried grains with solubles. Jones et al. (2010) found that galactosidase, galactomannanase, β-glucanase, or xylanase supplementation did not improve animal performance when added to corn–soybean meal–based diets containing 30% corn distillers dried grains with solubles. Neither Li et al. (1996) nor Ji et al. (2008) found growth improvement effects in swine from supplementing diets with a β-glucanase-protease blend, but Ji et al. (2008) did report an increase in DM, CP, crude fiber, crude fat, and ash digestibility. The efficacy of current generation carbohydrase enzymes appears to depend on the amount of available substrates for the enzymes to break down. Fiber substrate composition and concentration likely play a role in carbohydrase enzyme efficacy (Bedford, 2000). Therefore, a thorough understanding of the kernel composition, including the concentration and ratio of xylans, β-glucans, pectins, cellulose, lignin, and hemicellulose, should be acquired before making the determination to use carbohydrase enzymes in a swine diet.

In summary, nutrient composition and pig growth performance were similar between normal and drought-affected corn. Because nonstarch polysaccharide substrates were similar across dietary treatments, it was not surprising that enzyme inclusion showed little benefit to nursery pig growth performance; however, the improved feed efficiency of pigs fed diets containing Enzyme A from d 10 to 25 postweaning

| Item                         | Normal vs. drought-affected | Enzyme inclusion |
|------------------------------|----------------------------|------------------|
|                             | Normal | Drought | SEM | P= | None | A | B | A + B | SEM | P= |
| BW, kg                       |        |         |     |    |      |    |    |       |     |    |
| d 0                          | 5.83   | 5.83    | 0.003 | 0.912 | 5.84 | 5.83 | 5.83 | 5.83 | 0.004 | 0.573 |
| d 10                         | 6.71   | 6.71    | 0.048 | 0.991 | 6.71 | 6.71 | 6.71 | 6.71 | 0.067 | 0.989 |
| d 25                         | 11.81  | 11.65   | 0.149 | 0.474 | 11.60 | 11.97 | 11.62 | 11.73 | 0.211 | 0.591 |
| d 35                         | 17.43  | 17.20   | 0.203 | 0.438 | 17.26 | 17.66 | 17.07 | 17.26 | 0.287 | 0.520 |
| ADG, kg/d                    |        |         |     |    |      |    |    |       |     |    |
| d 10 to 25                   | 0.34   | 0.33    | 0.008 | 0.364 | 0.33 | 0.35 | 0.32 | 0.33 | 0.011 | 0.278 |
| d 25 to 35                   | 0.55   | 0.55    | 0.011 | 0.963 | 0.55 | 0.57 | 0.54 | 0.55 | 0.015 | 0.714 |
| d 10 to 35                   | 0.42   | 0.42    | 0.007 | 0.563 | 0.42 | 0.44 | 0.41 | 0.42 | 0.009 | 0.189 |
| ADFI, kg/d                   |        |         |     |    |      |    |    |       |     |    |
| d 10 to 25                   | 0.46   | 0.45    | 0.009 | 0.630 | 0.46 | 0.46 | 0.46 | 0.45 | 0.012 | 0.878 |
| d 25 to 35                   | 0.84   | 0.81    | 0.013 | 0.137 | 0.81 | 0.84 | 0.82 | 0.81 | 0.018 | 0.656 |
| d 10 to 35                   | 0.61   | 0.60    | 0.009 | 0.302 | 0.60 | 0.61 | 0.60 | 0.59 | 0.013 | 0.733 |
| G:F                          |        |         |     |    |      |    |    |       |     |    |
| d 10 to 25                   | 0.74   | 0.73    | 0.019 | 0.651 | 0.72 | 0.76 | 0.70 | 0.73 | 0.027 | 0.114 |
| d 25 to 35                   | 0.65   | 0.68    | 0.026 | 0.202 | 0.68 | 0.68 | 0.66 | 0.68 | 0.037 | 0.889 |
| d 10 to 35                   | 0.69   | 0.70    | 0.013 | 0.320 | 0.70 | 0.72 | 0.68 | 0.71 | 0.019 | 0.092 |
| ATTD, 3 %                    |        |         |     |    |      |    |    |       |     |    |
| DM                           | 85.3   | 85.2    | 0.39 | 0.847 | 85.6 | 85.6 | 85.1 | 84.8 | 0.55  | 0.652 |
| Ash                          | 51.6   | 53.1    | 1.38 | 0.474 | 48.2 | 56.3 | 50.2 | 54.7 | 1.95  | 0.018 |
| CP                           | 78.6   | 78.4    | 0.64 | 0.818 | 79.1 | 79.7 | 76.6 | 78.5 | 0.91  | 0.097 |
| Crude fat                    | 85.3   | 85.2    | 0.39 | 0.853 | 85.6 | 85.6 | 85.1 | 84.8 | 0.55  | 0.653 |
| Crude fiber                  | 53.7   | 48.0    | 1.52 | 0.013 | 50.3 | 48.1 | 54.4 | 50.7 | 2.14  | 0.213 |

1 A total of 360 barrows (PIC 1050 × 337; initially 21 d of age) were allotted to pens at weaning (d 0) and acclimated to a common phase 1 diet for 10 d. On d 10 after placement, pigs were weighed and pens of pigs were randomly allotted to 1 of 8 dietary treatments in a completely randomized design. There were 5 pigs per pen and 9 pens per treatment. Treatments were fed in 2 phases: Phase 2 from d 10 to 25 postweaning and Phase 3 from d 25 to 35 postweaning. Main effect interactions were not significant for any measured variable (P > 0.24) and were therefore removed from the model.

2 Enzyme A was Roxazyme G2G and Enzyme B was Ronozyme VP, both marketed by DSM Nutritional Products (Parsippany, NJ).

3 ATTD = apparent total tract digestibility. Calculated from analyzed feed and fecal samples collected on d 30 of the experiment and analyzed using titanium dioxide as an indigestible marker.
warrants further investigation, particularly in reference to xylan substrate availability.

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