RESEARCH REPORT
ANIMAL SCIENCE

Title: Maximizing the utilization of lower energy, higher fiber feedstuffs through more focused and effective use of xylanase – **NPB #14-234**

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Industry summary: This project speaks directly to the objective of the National Pork Board to "enhance nutrient extraction from low energy feedstuffs including but not limited to the effect of dietary factors on digestibility, gut function, and enzyme supplementation." With the growing demand for corn from ethanol and other industries, pork production has been using and will continue to use increased corn co-products in swine diets. These co-products are lower in energy and higher in fiber compared to corn. Therefore, the industry as a whole is presented with the challenge of maintaining productivity while feeding lower energy feedstuffs. Xylanases are enzymes that break down the hemicellulose component in plant fibers. By supplementing xylanase enzymes in the diet, it is hypothesized that the dietary fibers will be broken down, allowing the pig's natural enzymes access to trapped nutrients as well as the smaller broken down fiber fragments, thereby increasing digestibility. Improving digestibility of these lower energy, high fiber feedstuffs would allow pork producers to maintain production while feeding lower quality, cheaper feedstuffs. Understanding how the enzyme works within the body of the pig can help ensure the most appropriate use for the xylanase enzyme to achieve the best possible return on investment. This research will also help to determine whether an adaptation period is necessary for the xylanase enzyme to be effective, as has been previously suggested. Overall, this project aims to better understand how the xylanase enzyme works within the pig in order to provide the pork industry with guidance on when and how to use the enzyme most effectively.

Thirty-two gilts surgically fitted with T-cannulae at the end of the small intestine were randomly allotted into one of four dietary treatments on d 0 of the experiment, and remained on the same diets throughout the trial. Experimental diets were arranged in a 2 × 2 factorial with the first factor being fiber level (corn-SBM vs corn-SBM-30% DDGS), and the second factor being enzyme inclusion (no enzyme vs xylanase enzyme added at industry standard level). Three 5-day collections occurred during the trial (d 8 to 12, d18 to 22, d 38 to 42), each of which consisted of a 2-day fecal collection followed by a 3-day ileal collection. These collection times corresponded to body weights of approximately 4o kg, 60 kg and 80 kg.

This research found that xylanase inclusion increased energy digestibility in low fiber diets, but had no effect on energy digestibility in high fiber diets. Xylanase inclusion actually decreased fiber digestibility in the small intestine, regardless of fiber level in the diet. The inclusion of xylanase altered the pattern of energy digestibility

over the course of the trial; however the xylanase and non-xylanase treatments did not significantly differ from one another at any of the three collection periods. Xylanase inclusion did increase energy digestibility from d 20 to 40, whereas the non-xylanase treatment did not increase significantly. The question remains if this increase would have continued after 40 days, allowing the xylanase treatment to surpass the non-xylanase treatment.

Keywords: xylanase, swine, DDGS, digestibility, pigs

Scientific Abstract: Previous experiments with xylanase in swine have produced inconsistent and non-repeatable results. The objective of this experiment was to develop and understanding of the mode of action of the xylanase enzyme when used in diets based on corn fiber. Thirty-two gilts surgically fitted with t-cannula at the terminal ileum were randomly allotted to one of four dietary treatments, which they remained on for the duration of the trial. Diets were arranged in a 2 × 2 factorial, with fiber level being the first factor (corn-SBM or corn-SBM-30% DDGS) and xylanase being the second factor (0% or 0.017%). The trial consisted of three 5-day collections (d 8 to 12, d18 to 22, d 38 to 42), each of which included a 2-day fecal collection followed by a 3-day ileal collection. Chromic oxide was included in the diets as an indigestible marker. Data were analyzed using PROC MIXED with pig as the experimental unit, collection time as a repeated measure, and fiber level and xylanase inclusion as fixed effects. Xylanase inclusion tended to increase GE and DM digestibility in the small intestine in low fiber diets ($P = 0.058$, $P = 0.099$) but had no effect on energy digestibility in high fiber diets. Xylanase inclusion decreased NDF and ADF digestibility in the small intestine in low fiber diets ($P = 0.008$, $P = 0.001$), and decreased hemicellulose digestibility in the small intestine regardless of dietary fiber level ($P = 0.020$). Inclusion of xylanase increased ADF digestibility in the large intestine, regardless of dietary fiber level ($P = 0.106$). The pattern of energy and ADF digestibility over time was altered by the inclusion of xylanase. Although the non-xylanase and xylanase treatments were not different from one another at each of the three time points, non-xylanase treatments had significant increases in GE digestibility from d 10 to 20, followed by no significant increase from d 20 to 40, whereas treatments containing xylanase had no change in digestibility from d 10 to 20, but significant changes in ADF and GE digestibility from d 20 to 40. Xylanase appears to be more effective in low fiber diets and after some amount of time on the enzyme.

Introduction: The growth of the ethanol industry in the United States has increased competition for corn, leading to the increased use of corn co-products in many livestock diets, including swine. Dried distillers grains with solubles (DDGS) have become a particularly popular feed ingredient in swine diets, allowing the swine industry to reduce cost and demand for corn. DDGS are higher in non-starch polysaccharides and lower in digestible energy when compared to corn, which causes a challenge for producers to maintain pig performance while feeding these co-products.

The gastrointestinal tract of the pig does not have sufficient endogenous enzymes to break down the high amount of non-starch polysaccharides found in diets containing DDGS. Xylanase enzymes have been shown to break arabinoxylans, a component of plant fibers, down to arabinose and xylose units. It is assumed that the breakdown of these non-starch polysaccharides into their individual units improves dietary energy values of these feedstuffs. However, previous trials using xylanase in pigs from the nursery through the growing phase have produced inconsistent and non-repeatable results. In order to ensure the appropriate and most cost-effective use of the xylanase enzyme, information is needed as to how the enzyme works within the gastrointestinal tract of the pig, and how the pig then utilizes the products of that reaction.

The objective of this study was to develop and understanding of the action of the xylanase enzyme within the gastrointestinal tract of the pig. The hypothesis was that the xylanase enzyme breaks down the arabinoxylan component of corn fiber into arabinose and xylose units, which are then available to the pig, thereby increasing digestibility of these higher fiber corn co-products.

Objectives: The overall objective of this proposal was to develop and understanding of the mode of action of the xylanase enzyme when used in diets based on corn fiber. In particular, this proposal aimed to improve

understanding of the action of the xylanase enzyme within the gastrointestinal tract of the pig, and better understand how the pig is able to utilize the products of this enzyme reaction. The specific objectives were:

1. To measure the impact of exogenous xylanase on the flow of energy through the small and large intestines.
2. To measure the impact of exogenous xylanase on apparent digestibility – in the small intestine, large intestine, and over the full digestive tract – of the following dietary constituents: dry matter, energy, nitrogen, starch, ether extract, ADF, and NDF.
3. To determine the time course of response to the enzyme treatment on the above measurements.
4. To use a high degree of replication in the study, to assure our ability to detect relatively small but biological and financially important changes in the measurements described in objectives 1 and 2 above.

Materials and Methods

All procedures for this experiment were approved by the Institutional Animal Care and Use Committee at Iowa State University, IACUC Log # 1-15-7918-S.

Animals, Housing, and Experimental Design

Two groups of sixteen gilts with an average initial BW of 32.6 ± 0.47 kg were surgically fitted with a T-cannula at the terminal ileum following procedures described by Stein et al. (1998), for a total of thirty-two gilts on test. The first group of pigs were progeny of sire line 600 × dam line C22 (DNA genetics, Columbus, NE), and the second group were half progeny of Camborough sire x 280 dam, and half sire line C29 × dam line 280 (Pig Improvement Company North America, Hendersonville, TN).

Following surgery, pigs were housed in individual pens (1.8 by 1.9 m) with half slatted floors. Each pen was equipped with a stainless steel feeder and nipple drinker, and pigs were allowed ad libitum access to water through the trial. Pigs were allowed to recover from surgery for at least seven days, during which time they were allowed ad libitum access to feed and water. After recovering from surgery, pigs were weighed (37.5 ± 0.33 kg) and randomly allotted to one of 4 dietary treatments, which they remained on for the duration of the trail. The trial consisted of three collection periods, which included 2 d of fecal subsample collections followed by 3 d ileal digesta subsample collections.

Dietary Treatments

A basal corn-soybean meal diet was formulated to meet growing pig requirements as established by the NRC (NRC 2012). Three other dietary treatments were obtained by adding DDGS (Poet Biorefining, Jewell, IA) and/or the xylanase enzyme at the expense of corn (Table 1). Four dietary treatments were arranged in a 2 × 2 factorial, with low fiber (**LF**; 0% DDGS) or high fiber (**HF**; 30% DDGS) as the first factor, and the inclusion of xylanase at 0% or 0.017% of the diet as the second. The source of xylanase was AB Vista Econase XT and was included at 150g xylanase/1 ton (US) finished feed. Diets included chromic oxide (Cr_2O_3) at 0.4% as an indigestible marker. Pigs remained on the same dietary treatment through all three-collection periods during the experiment, for a total of 24 observations per treatment.

On d 0, pigs were weighed and allotted to treatments according to a randomized complete block design. Pigs were fed 90% ad libitum feed intake calculated using the average pig BW on d 0. Pig weights were also measured on d 12, 22, and 42, and the amount fed was adjusted using the new average pig BW on d 13 and 23 accordingly. Pigs were fed twice daily at approximately 0800 h and 1600 h.

Fecal samples were collected via grab sampling following 0800 h and 1600 h feedings on d 8 to 9, 18 to 19, and 38 to 39. Samples were stored in a -20°C freezer immediately after each collection. At the end of the collection period, samples were thawed and homogenized within animal, and subsamples were taken for laboratory analysis. Subsamples were oven dried in a convection oven for 3 days at 65°C. Dried samples were ground to 1 mm using a Variable Speed Digital ED-5 Wiley Mill, then stored in a desiccator.

Ileal samples were collected through the cannula on d 10 to 12, 20 to 22, and 40 to 42 from 0800 h to 1600 h, for a total of eight hours each day. The night before collections, contents inside of cannulas were cleaned out to

ensure a representative sample was collected. For ileal digesta collections, sterile 207-mL plastic collection bags (Whirl-Pak; Nasco, Fort Atkinson, WI) were attached to the end of the cannula via zip ties and were changed when they became ¾ full or every hour, whichever occurred first. As soon as a bag was removed from the cannula, it was closed with the zip tie and immediately placed in a -20°C freezer to prevent bacterial degradation. At the end of the collection period, samples from all three days were thawed, homogenized within animal, and subsampled. Subsamples were then frozen for storage until samples could be dried. Ileal samples were lyophilized for approximately 7 days at -55°C. Dried samples were ground to 1 mm using a Variable Speed Digital ED-5 Wiley Mill, then stored in a desiccator.

Subsamples of each dietary treatment and dietary ingredient were collected during feed mixing. Samples were homogenized, ground to 1 mm using a Retsch grinder, then stored in a desiccator.

Chemical Analysis and Calculations

Samples of diets, ileal digesta, and fecal material were analyzed for DM (method 930:15; AOAC, 2007) ether extract (EE; method 920:39; AOAC 2007), N using the combustion method (method 990.03; AOAC, 1990) with a Trumac apparatus (Leco Corporation, St. Joseph, MI) with EDTA for calibration (9.58 ± 0.01% N; Leco Corporation), ADF (Ankom fiber analyzer, A2000, A2001), NDF (Ankom fiber analyzer, A2000, A2001), and chromic oxide (Fenton and Fenton, 1979) measuring absorption at 440 nm using a spectrophotometer (Synergy 4: BioTek, Winooski, VT). The GE of diets, ileal digesta, and fecal samples were determined using bomb calorimetry (Parr 6200 calorimeter; Parr Instruments Co., Moline, IL). Benzoic acid (6,318 kcal GE/kg; Parr Instruments Co.) was used as the standard for calibration, and was determined to contain 6,328 ± 1.68 GE/kg. Diet and ileal samples were also analyzed for starch (method 996.11; AOAC, 2007). Dietary ingredients, diets, and ileal samples were analyzed for amino acids (Ajinimoto Heartland North America, Chicago, IL). Diets were analyzed for xylanase content (AB Vista Enzyme Services, Cordova, TN) and dietary ingredients were analyzed for particle size (Kansas State University, Manhattan, KS).

For each dietary treatment, the apparent ileal digestibility (AID) and apparent total tract digestibility (ATTD) for DM, GE, NDF, ADF, EE, and N, and the AID of AA and starch were calculated using the index method (Oresanya et al., 2008):

> AID/ATTD% = 100% - [(chromic oxide concentration in diet)(component concentration in sample)/(component concentration in diet)(chromic oxide concentration in the sample) × 100].

Hemicellulose was calculated as the difference between NDF and ADF measurements. The amount of dietary components remaining at the terminal ileum and the amount excreted in feces was determined using the following calculations (Pilcher et al., 2014):

> Amount remaining at terminal ileum = [concentration of component in digesta × (chromic oxide in diet/chromic oxide in digesta)] and
>
> Amount excreted in feces = [concentration of component in feces × (chromic oxide in diet/chromic oxide in feces)].

These calculations were then used to determine disappearance before the terminal ileum and hindgut disappearance:

> Disappearance before the terminal ileum = (intake – amount remaining at terminal ileum) and
>
> Hindgut disappearance = (amount remaining at terminal ileum – amount excreted in feces).

Statistical Analysis

All data were analyzed using the MIXED procedure of SAS (PROC MIXED; SAS 9.3, Cary, NC). Fiber level and enzyme inclusion were the main effects. Pig was the experimental unit, and replicate was the random effect. Collection time was the repeated measure. The model included all possible interactions among fiber level, enzyme inclusion, and collection time.

Results: ***Flow of energy through the small intestine and large intestine***
Xylanase inclusion decreased GE digestibility in the small intestine in HF diets from d 8 to 12 (Figure 1) and d 18 to 22 (Figure 2)**,** and had no effect on GE digestibility in the small intestine from d 38 to 42 (Figure 3). Xylanase increased GE digestibility in the large intestine from d 8 to 12 and d 38 to 42, but decreased GE digestibility in the large intestine from d 18 to 22 compared to the HF diet without xylanase. In LF diets, xylanase inclusion increased GE digestibility in the small intestine at all three collection times. Diets including xylanase had lower GE digestibility in the large intestine from d 8 to 12 and 18 to 22, but had higher GE digestibility in the large intestine from d 38-42.

Dietary fiber and xylanase effects on digestibility measured in the small intestine
GE and DM digestibility tended to increase with xylanase inclusion in LF diets ($P = 0.058$, $P = 0.099$), while there was no effect of xylanase inclusion on GE and DM digestibility in HF diets ($P > 0.100$), resulting in an interaction between xylanase inclusion and fiber level for GE ($P = 0.011$) and DM ($P = 0.020$) digestibility (Table 3).

NDF and ADF digestibility was decreased due to xylanase inclusion in LF diets ($P = 0.008$, $P = 0.001$), while xylanase inclusion had no effect on NDF or ADF digestibility in HF diets; this led to an interaction between xylanase and fiber level for NDF ($P = 0.027$) and ADF ($P = 0.004$) digestibility (Table 3). Xylanase inclusion decreased hemicellulose digestibility, regardless of fiber level ($P = 0.020$; Table 2).

Fat digestibility was increased due to xylanase inclusion in HF diets on d 10 and 20, and in LF diets on d 40, while fat digestibility was decreased due to xylanase inclusion in HF diets on d 40 and in LF diets on d 10 and 20, resulting an interaction among xylanase inclusion, dietary fiber amount, and time ($P < 0.058$).

Dietary fiber and xylanase effects on digestibility measured in the large intestine
DM digestibility was increased by inclusion of xylanase in HF diets, while DM digestibility decreased with xylanase inclusion in LF diets, leading to an interaction between fiber level and xylanase inclusion ($P = 0.029$). There was a trend for the same interaction in GE digestibility, with xylanase inclusion tending to decrease GE digestibility in LF diets and tending to increase GE digestibility in HF diets ($P = 0.085$; Table 3). NDF, hemicellulose, and EE digestibility were not affected by xylanase inclusion. ADF digestibility in the hindgut tended to increase with the inclusion of xylanase ($P = 0.106$; Table 2).

Dietary fiber and xylanase effects on digestibility measured over the full digestive tract
GE, DM, NDF, fat, and hemicellulose digestibility across the total tract were not impacted by xylanase inclusion ($P > 0.100$). As would be expected, HF diets had lower GE and DM digestibility compared to LF diets ($P < .001$; Table 2). ADF digestibility was increased by inclusion of xylanase in HF diets, but decreased in LF diets, resulting in an interaction between fiber level and xylanase inclusion ($P = 0.047$; Table 3).

Dietary fiber and xylanase effects on amino acid digestibility in the small intestine
Xylanase inclusion increased the digestibility of arginine and cysteine ($P \leq 0.037$), and tended to increased valine digestibility ($P = 0.103$) in the small intestine. Xylanase inclusion decreased the digestibility of asparagine and glutamic acid in the small intestine in HF diets, but increased digestibility of these amino acids in LF diets, resulting in an interaction between xylanase inclusion and fiber level ($P \leq 0.040$). Leucine and lysine digestibility in the small intestine tended to follow the same interaction ($P \leq 0.093$). Alanine and proline digestibility increased in HF diets compared to LF ($P \leq 0.004$), and glycine digestibility tended to increase in HF diets ($P = 0.061$). Arginine, cysteine, histidine, isoleucine, methionine, phenylalanine, serine, threonine,

tryptophan, and valine digestibility were all increased in LF diets compared to HF diets ($P \leq 0.003$). Fiber level and xylanase inclusion had no effect on tyrosine digestibility.

Time course response to xylanase treatment
Xylanase inclusion had no effect on DM and GE digestibility from collection 1 (d 8 to 12) to collection 2 (d 18 to 22), however xylanase inclusion increased DM and GE digestibility from collection 2 to collection 3 (d 38 to 42; Figure 4). ADF digestibility across the total tract was increased by xylanase inclusion from collection 2 to collection 3 (Figure 5). There was no effect of xylanase inclusion on ADF digestibility from collection 1 to collection 2. Diets not including xylanase had increased DM, GE, and ADF digestibility from collection 1 to collection 2 compared to diets containing xylanase, however both treatments were not different at collection 3.

Discussion: The xylanase enzyme cleaves the xylan linkages in arabinoxylans, which are a component of hemicellulose. Our hypothesis was that inclusion of the xylanase enzyme would break down these components in the hemicellulose portion of the diet, opening up the structure of the fiber and allowing endogenous enzymes to gain access to trapped nutrients and possibly the oligosaccharide products of the enzyme reaction. In this study, we saw that xylanase inclusion actually decreased hemicellulose digestibility in the small intestine, regardless of dietary fiber level. This indicates that although the hemicellulose components may be being broken down in the small intestine, this is not making them available for digestion.

Fat and amino acid digestibility we measured to test if xylanase inclusion released these trapped nutrients within the fiber structure. Fat digestibility was not impacted by xylanase inclusion. Xylanase inclusion increased digestibility of arginine, cysteine, and tended to increase digestibility of valine, however all other amino acids were not impacted by xylanase inclusion; dietary fiber level had a much larger impact on amino acid digestibility.

Xylanase inclusion did increase digestibility of ADF in the large intestine. This may have been a result of the xylanase enzyme breaking down the hemicellulose component of fiber, thereby weakening the fiber structure and allowing other endogenous enzymes to break down trapped nutrients and/or components of ADF for digestion. However, digestion and nutrient absorption in the large intestine is much less efficient compared to digestion and nutrient absorption in the small intestine, which brings into question the amount of BW gain that would occur due to this increase in digestibility.

In this study, the effects of xylanase supplementation on digestibility were almost entirely dependent on fiber level in the diet. Xylanase supplementation in LF diets tended to increase energy digestibility in the small intestine, but decreased fiber digestibility in the small intestine. There was little effect of xylanase on digestibility in the small intestine in HF diets, other than decreased hemicellulose digestibility, which occurred regardless of dietary fiber level.

When mapped over time, xylanase inclusion did result in different pattern of GE and ADF digestion. Although the two treatments were not significantly different at any of the three time points, there is a clear change in pattern of digestion. Diets not including xylanase had an increase in GE digestibility between d 10 and 20, but then digestion leveled off from d 20 to d 40. Diets containing xylanase showed no change in GE or ADF digestibility from d 10 to 20, but had significantly increased GE and ADF digestibility from d 20 to 40. The question following this trial is do these slopes continue after 40 days on the enzyme, resulting in improved energy and fiber digestibility? If so, what occurs during this adaptation period to make the enzyme more effective?

In summary, xylanase inclusion impacted digestibility differently depending on dietary fiber levels. In LF diets, xylanase tended to increase energy digestibility in the small intestine, but decreased fiber digestibility in the small intestine. In HF diets, the only effect of xylanase inclusion was decreased hemicellulose digestibility. The decrease in hemicellulose digestibility indicates that although xylanase may be breaking down the hemicellulose component of fiber in the diet, these enzyme reaction products are not being digested and

absorbed into the body of the pig. Our results looking at xylanase over time indicate that xylanase is in fact altering digestibility, but more research is needed to determine whether these slopes continue after time on the enzyme.

Table 1. Ingredient composition (as-fed basis) of the experimental diets

Item	LF no xylanase	LF with xylanase	HF no xylanase	HF with xylanase
Ingredient, %				
Corn	77.730	77.713	50.680	50.663
Reduced-oil DDGS	0.000	0.000	30.000	30.000
Soybean meal (47.7% CP)	18.400	18.400	16.000	16.000
Chromic oxide	0.400	0.400	0.400	0.400
Limestone	1.180	1.180	1.450	1.450
Monocalcium Phosphate	0.940	0.940	0.350	0.350
Salt	0.250	0.250	0.250	0.250
L-lysine HCL	0.450	0.450	0.440	0.440
DL-methionine	0.060	0.060	0.000	0.000
L-threonine	0.130	0.130	0.020	0.020
L-tryptophan	0.020	0.020	0.010	0.010
L-valine	0.040	0.040	0.000	0.000
Vitamin premix[1]	0.250	0.250	0.250	0.250
Trace mineral premix[2]	0.150	0.150	0.150	0.150
Econase XT	0.000	0.017	0.000	0.017
Analyzed Composition				
DM, %	90.24	90.63	90.42	90.67
GE, Mcal/kg	3.83	3.84	4.01	4.03
CP (N × 6.25), %	14.10	14.25	19.53	20.07
Crude Fat, %	3.09	3.07	4.31	4.30

[1]Provided per kilogram of complete diet: vitamin A, 6,614 IU; vitamin D, 827 IU; vitamin E, 26 IU; vitamin K, 2.6 mg; niacin, 29.8 mg; pantothenic acid, 16.5 mg; riboflavin, 5.0 mg; vitamin B12, 0.023 mg.

[2]Provided per kilogram of diet: Zn, 165 mg as zinc sulfate; Fe, 165 mg as iron sulfate; Mn, 39 mg as manganese sulfate; Cu, 17 mg as copper sulfate; I, 0.3 mg as calcium iodate; and Se, 0.3 mg as sodium selenite.

Table 2. Effect of fiber level and xylanase inclusion on digestibility in the small intestine, large intestine, and over the total tract

	Fiber		Xylanase			*P-Value*		
Item	LF	HF	No	With	SEM	Fiber	Xylanase	Fiber × Xylanase
Ileal digestibility								
Hemicellulose %	15.79	16.81	18.51	14.09	0.092	0.586	0.0	0.011
Fat %	59.97	69.30	65.15	64.12	0.998	<.001	0.466	0.679
Hindgut digestibility								
NDF %	1.76	2.74	2.11	2.39	0.144	<.001	0.177	0.813
ADF %	0.95	1.31	1.06	1.20	0.059	<.001	0.106	0.970
Hemicellulose %	0.81	1.43	1.05	1.19	0.092	<.001	0.275	0.694
Fat %	-0.82	-0.74	-0.79	-0.77	0.043	0.228	0.801	0.923
Total tract								
GE %	83.87	77.74	80.71	80.90	0.229	<.001	0.567	0.407
DM %	85.48	78.72	82.01	82.19	0.196	<.001	0.520	0.520
NDF %	40.41	40.24	40.39	40.26	0.754	0.875	0.906	0.446
Hemicellulose %	35.18	34.30	34.93	34.55	1.647	0.450	0.741	0.860
Fat %	35.72	53.71	44.92	44.50	1.687	<.001	0.646	0.940

Table 3. Effects of fiber level and xylanase inclusion interactions on digestibility in the small intestine, large intestine, and over the total tract

						P-Value		
Item	LF no xylanase	LF with xylanase	HF no xylanase	HF with xylanase	SEM	Fiber	Xylanase	Fiber × Xylanase
Ileal digestibility								
DM %	72.70	74.52	65.56	64.77	0.355	<.001	0.310	0.011
GE %	72.90	74.62	67.60	66.84	0.369	<.001	0.361	0.020
NDF %	18.84	10.39	19.49	18.63	1.286	0.017	0.012	0.040
ADF %	18.03	7.48	22.63	23.15	1.320	<.001	0.009	0.004
Hindgut digestibility								
DM %	11.48	10.07	12.55	13.37	0.353	<.001	0.553	0.029
GE (Mcal/kg)	0.46	0.40	0.45	0.48	0.017	0.119	0.635	0.085
Total tract								
ADF %	49.90	47.51	49.09	51.64	0.864	0.179	0.951	0.047

Figure 1. GE flow through the gastrointestinal tract measured from d 8 to 12

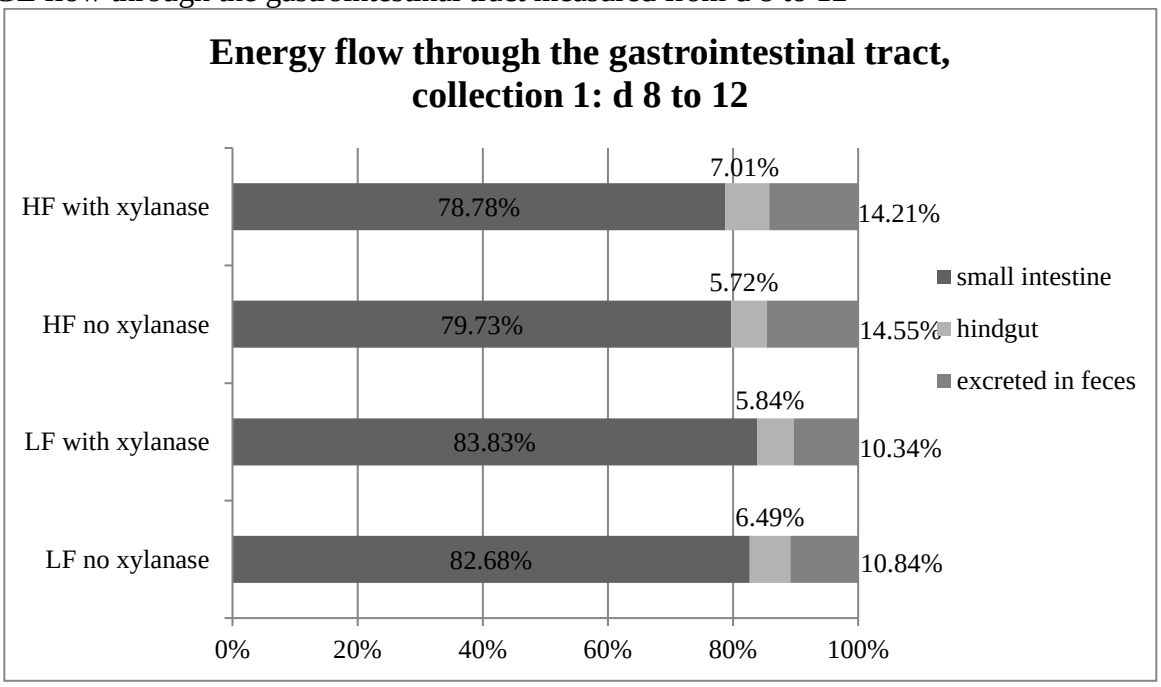


Figure 2. GE flow through the gastrointestinal tract measured from d 18 to 22

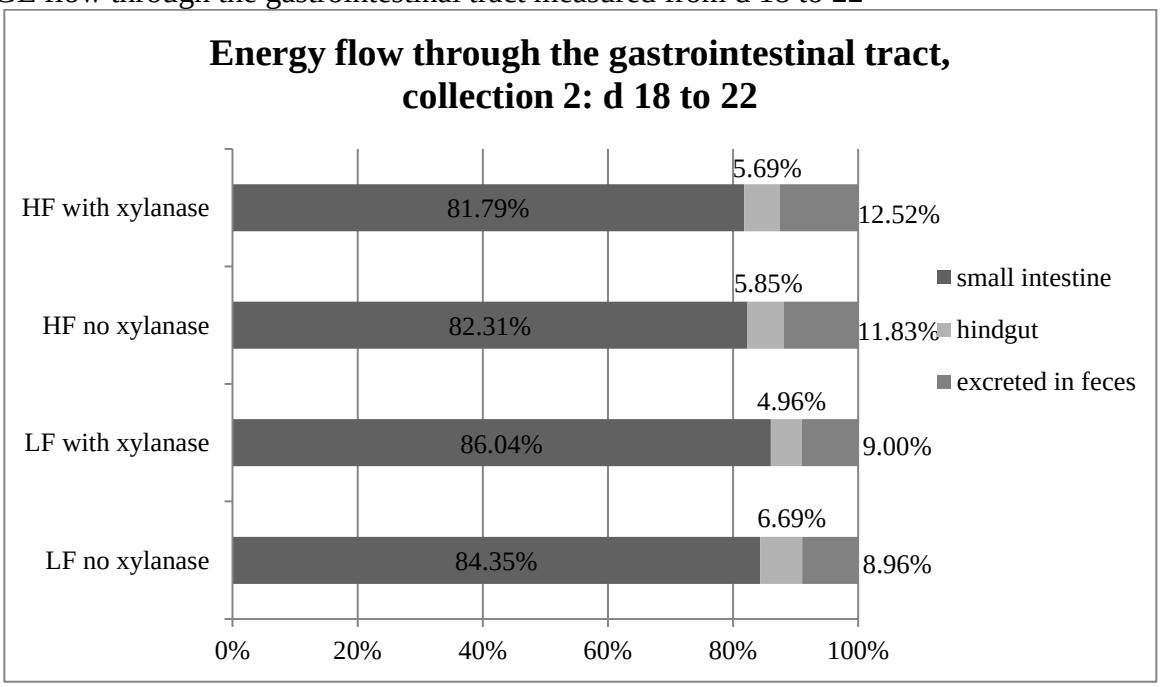


Figure 3. GE flow through the gastrointestinal tract measured from d 38 to 42

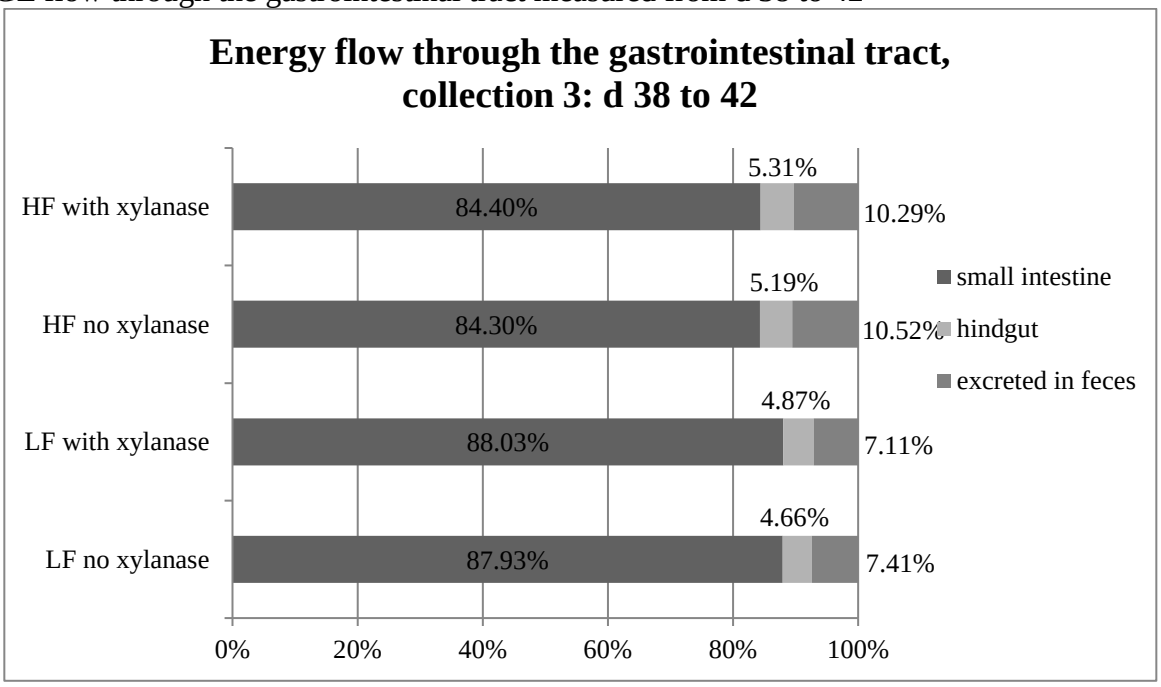
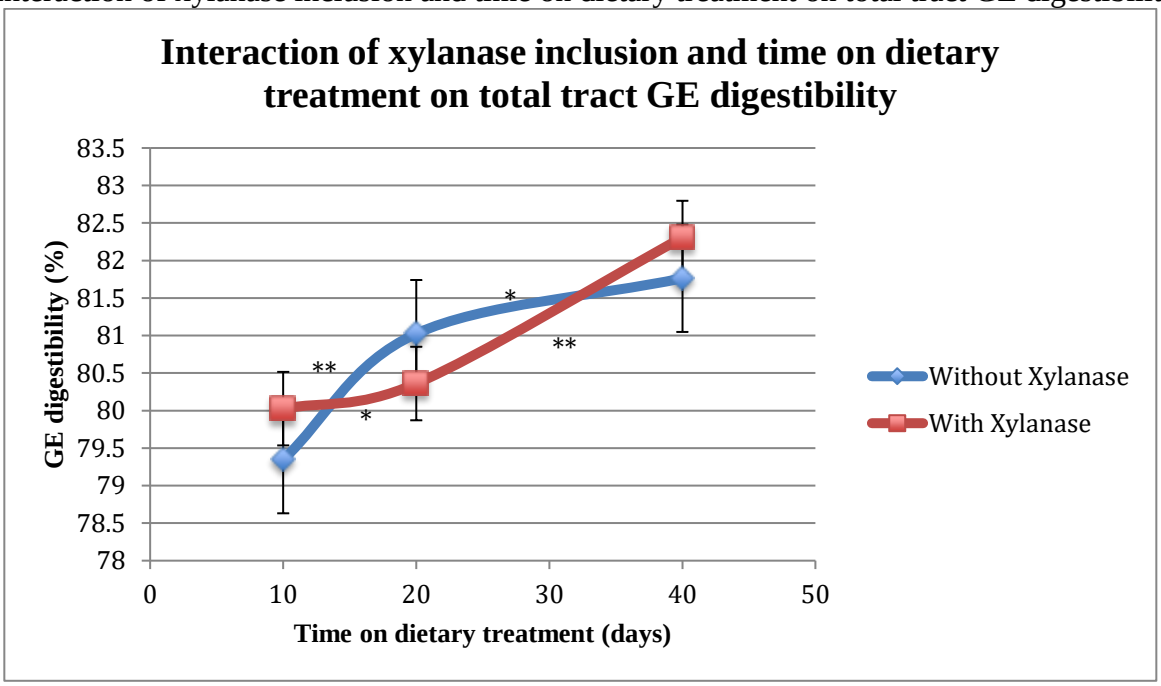
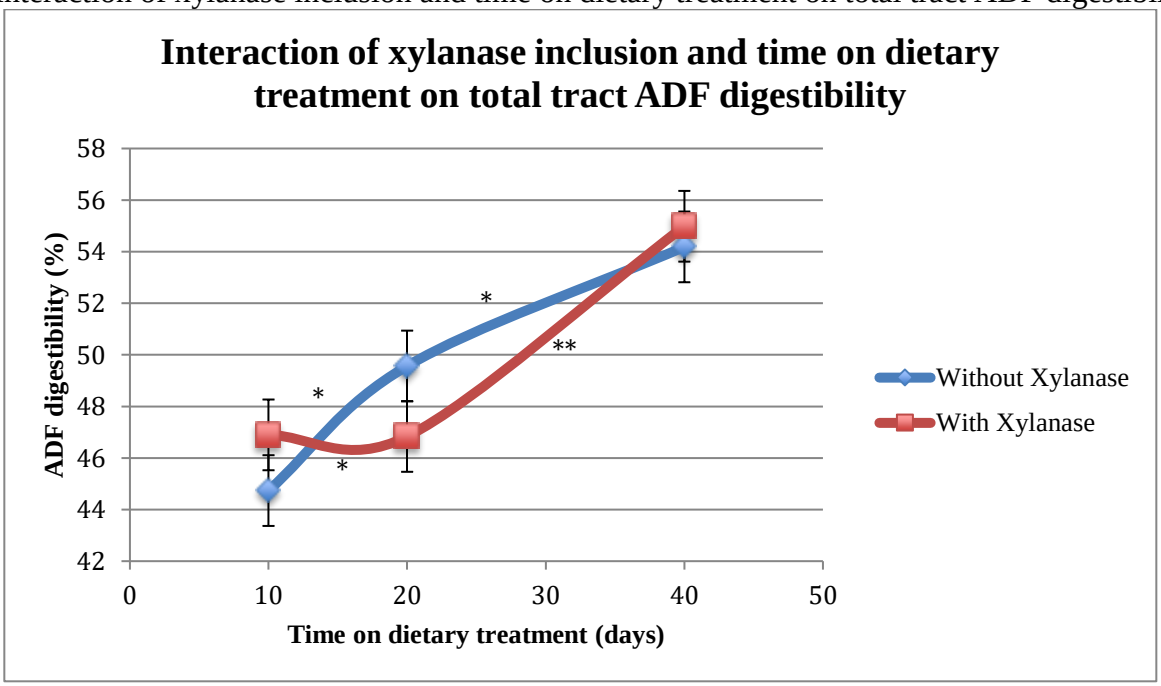


Figure 4. Interaction of xylanase inclusion and time on dietary treatment on total tract GE digestibility



*No significant difference (P > 0.05)
**Significant difference (P < 0.05)

Figure 5. Interaction of xylanase inclusion and time on dietary treatment on total tract ADF digestibility



*No significant difference (P > 0.05)
**Significant difference (P < 0.05)