Sci Forschen
Open HUB for Scientific Research

Journal of Animal Science and Research
ISSN 2576-6457 | Open Access

RESEARCH ARTICLE

Volume 3 - Issue 1 | DOI: http://dx.doi.org/10.16966/2576-6457.124

Evaluating the Effect of Adaptation Length on Apparent Ileal and Total Tract Digestible Energy of Corn and Wheat Middlings in Growing Pigs

Adedokun SA*, Olojede OC, Dong K and Harmon DL

Department of Animal and Food Sciences, University of Kentucky, Lexington, Kentucky, USA

***Corresponding author:** Sunday A Adedokun, University of Kentucky, Department of Animal and Food Sciences, WP Garrigus Bldg, Lexington, KY, USA, E-mail: tayo.adedokun@uky.edu

Received: 22 Jan, 2019 | **Accepted:** 22 Feb, 2019 | **Published:** 01 Mar, 2019

Citation: Adedokun SA, Olojede OC, Dong K, Harmon DL (2019) Evaluating the Effect of Adaptation Length on Apparent Ileal and Total Tract Digestible Energy of Corn and Wheat Middlings in Growing Pigs. J Anim Sci Res 3(1): doi doi dx.doi.org/10.16966/2576-6457.124

Abstract

This study investigates the effect of adaptation length of corn- and wheat middlings (WM)-based diets on apparent ileal and total tract digestible energy (DE) of corn and WM using the difference method. Twenty-one ileal cannulated pigs (BW=34.1 ± 1.5 kg) were allotted in a 3 × 3 factorial arrangement of treatments using the randomized complete block design with 3 diets (reference, reference+corn, or reference+WM) and 3 adaptation lengths (4, 8, and 12 days). Each pig was fed 4% of the BW of the lightest pig within each block. Reference+corn and reference+WM diets were produced by replacing 30% of the energy yielding components of the reference diet (corn-SBM-based) with corn or WM, respectively. Ileal and fecal samples were collected on days 4, 8, and 12. Proc mixed model of SAS was used to analyze the data and a repeated statement was included to account for correlated observations made on the same animal. The main effect of diet type on ileal and total tract DE, dry matter (DM) and energy (EN) digestibility was different with reference+WM diet having lower (P<0.05) values. Diets total tract DE (2.7%), DM (2.6%) and EN (2.8%) digestibility increased (P<0.05; linear and quadratic effect) with increasing adaptation length. Ileal (3,325 *vs* 1,778 kcal/kg) and total tract (3,668 *vs* 2,864 kcal/kg) DE of corn was higher (P<0.05) than that of WM. Hindgut EN disappearance showed a tendency to increase (P=0.051) linearly with adaptation length (index method). Energy loss in the hindgut from the reference+WM diet was higher (P<0.05) compared to that of the reference diet (subtraction method). Data from this study showed that the DE of corn and WM increased by 10 and 61%, respectively, between the ileal and total tract values. Finally, four days of adaptation is sufficient for corn and WM ileal and total tract DE determination.

Keywords: Adaptation length; Corn; Digestible energy; Pig; Wheat middlings

Introduction

Diet provides livestock with energy and nutrients and like nutrients, energy plays an important role in the performance, health, and wellbeing of an animal. In order to optimally utilize nutrients and energy in a diet, the relationships between the compositions of raw feed ingredients and the changes they undergo in the gastrointestinal tract (GIT) are crucial to understanding the extent to which such feed ingredient can be utilized. The chemical composition of any diet is a function of the characteristics of the ingredients that make up the diet. These characteristics are influenced by several components of the diet including crude protein, lipid, starch, crude fiber, as well as the proportion of the non-starch polysaccharides (NSP). Energy is an important constituent of feeds that are given to swine; however, meeting the pig's requirement for energy is confounded by the fact that protein, starch, fat, and, to some extent, fiber are utilized as energy sources with different degrees of efficiency. Metabolically, sugar from carbohydrate is the most efficient source of energy. Conversely, fiber and protein are less efficient energy sources because they are promptly catabolized rather than held in tissues for various intermediate metabolic activities resulting in heat increment [1]. On this basis, corn has been consistently used as a source of energy because it contains high levels of starch and fat, (compared to soybean meal [SBM]) and relative to other feed ingredients, lower levels of fiber and protein. As such, can undergo metabolic transformations to be utilized for bodymaintenance functions or growth of muscle tissue without resulting in a significant energy loss due to heat increment [1]. Other cereal grains like sorghum, wheat, rye, and barley have relatively lower nutritive value. However, the competition for cost savings in the industry as well as the improvement in feed technology such as the availability of exogenous enzymes, makes the inclusion of non-traditional cereal grains in non-ruminant animal diets more attractive to nutritionists. Thus, farmers are progressively replacing pig feeds with inexpensive cereal grain byproducts like distillers dried grain with solubles (DDGS), wheat middlings (WM), and dried bakery meal.

The inclusion of these byproducts (such as DDGS) in a corn SBM-based diet will affect the chemical composition of the pig's diet resulting in less starch or disaccharide fractions and more fibrous polysaccharides often called non-starch polysaccharides (NSP). The majority of NSP is often comprised of cellulose, pectins, β-glucans, pentosans, heteroxylans, and xyloglucan [2] and cannot be broken down by the endogenous enzymes of humans and monogastric animals [2-4]. These consequently lead to anti-nutritive effects in pigs. One of the established effects of NSP in pig's nutrition is its influence on prececal digestion and absorption of nutrients and energy. The dietary fiber components that are not digested by endogenous digestive enzymes, serve as substrates for bacterial fermentation in the distal section of the GIT. Hence, diet with high NSP increases hindgut microbial activity, heat increment, and subsequently total tract digestible energy (DE) as a result of hindgut fermentation [5,6]. The inability of pigs to efficiently utilize dietary fiber makes the impact of fiber on dietary energy value in pigs important. The effects of dietary fiber on diets and feed ingredient's DE value, feed intake, gut fill, and water holding capacity of the digesta have been reported [6]. Undigested fibers are rich sources of energy for hindgut microbes and it has been reported that dietary fiber plays an important role in how much energy the pig can extract from its diet. The higher the dietary fiber, the lower the amount of DE that is available to the pig [7,8] and the lower the amount of energy (EN) that is available to the growing pig [9,10]. It has also been reported that with increasing age of a pig, fiber digestibility increases [11]. Furthermore, fiber digestibility increases as the digesta moves from the midgut to the large intestine [12], however, the extent to which the pig is able to handle fiber from different sources differs.

Noblet and Bach Knudsen [11] reported that the digestibility of fiber fractions from corn (74%) and soybean pulp (86%) was higher than that of wheat bran (46%) in sows. Based on this, both the level of inclusion of fiber in the diet as well as the source of the fiber should be considered when formulating diets for swine. In general, EN digestibility of feeds and feed ingredients are determined after the pigs have been exposed to the diets for certain number of days. The adaptation length (AL) may be as low as 7 to as long as 10 [13] or in certain cases up to 28 days [14]. Linear increase with increasing AL has been reported [14]. The AL that has been frequently reported in the literature for pigs is around 7 days; hence, it is important to investigate whether a shorter or longer AL is required for optimal ileal or total tract DE of corn and wheat middlings (WM). The crude fiber contents of corn and WM are different. Hence, AL of 4, 8, and 12 days will be investigated with the hypothesis that DE of corn and WM will increase with increasing AL. Therefore, the objective of this study was to investigate the effect of different AL to the experimental diets on ileal and total tract DE value of diets differing widely in dietary fiber content. The two feed ingredients, corn and WM, were selected for this study based on their different levels of crude fiber (15 *vs* 89 g/kg).

Materials and Methods

All protocols used in this study were approved by the University of Kentucky Animal Care and Use Committee.

Pigs and experimental diets

Twenty-one weanling crossbred barrows (Yorkshire × Duroc × Chester White) were fitted with simple T-cannula approximately 6 cm anterior to the ileo-cecal-colonic junction as previously described [15]. Prior to the current study, the pigs had been used in two earlier studies and were allowed a two-week rest period before the start of the current study. The average initial BW of pigs used in this study was 34.1 ± 1.54 kg. Pigs were allotted to a 3 × 3 factorial arrangement of treatments using the randomized complete block design with 3 diets (reference, reference+corn, or reference+WM-based) and 3 adaptation periods (4, 8, and 12 days). Pigs were blocked by body weight with each block consisting of 3 pigs (a total of 7 blocks). Each dietary treatment was repeated once within each block.

Table 1: Composition of the experimental diets fed to the growing pigs (on as-fed basis).

	Dietary treatment		
Ingredients, g/kg	**Reference**	**Reference+corn**	**Reference+wheat middlings**
Corn	630.4	435.5	435.5
Soybean meal	290.0	199.6	199.6
Corn	0.0	300	0.0
Soyoil	47.0	32.4	32.4
Wheat middlings	0.0	0.0	300
Lysine HCl	1.6	1.6	1.6
DL Methionine	0.5	0.5	0.5
L-Threonine	0.5	0.5	0.5
Limestone	9.0	9.0	9.0
Dicalciumphosphate	10.4	10.4	10.4
Salt (NaCl)	3.1	3.1	3.1
Vitamin premix[1]	1.0	1.0	1.0
Tracemineral premix[2]	1.5	1.5	1.5
Titanium dioxide[3]	5.0	5.0	5.0
Total	1,000	1,000	1,000

[1]Vitamin premix supplied the following per kilogram of diet: 11,000 IU of vitamin A; 1,100 IU of vitamin D; 77 IU of vitamin E; 2.2 mg of vitamin K; 1.65 mg of thiamin; 8.25 mg of riboflavin; 30.25 mg of niacin; 27.50 mg of pantothenic acid; 4.95 mg of vitamin-6; 0.36 mg of biotin; 4.95 mg of folic acid; and 0.03 of vitamin B-12

[2]Trace mineral premix supplied the following per kilogram of diet: 50 mg as manganese sulfate monohydrate; 100 mg of Fe as ferrous sulfate monohydrate; 125 mg of Zn as zinc sulfate monohydrate; 20 mg of Cu as copper sulfate; 0.35 mg of I as calcium iodate; and 0.30 mg of Se as sodium selenite

[3]Added to the diets as an indigestible marker for digestibility calculation

The experimental diets are as shown in table 1. The reference diet was corn-SBM based which met or exceeded energy and nutrient requirements of pigs at this age [16]. Thirty percent of the energy yielding components of the reference diet (corn, SBM, and soy oil) was replaced with either corn (diet 2) or WM (diet 3) in such a way that their ratios were similar across all dietary treatments. This is important in order to fulfil the basis on which the apparent metabolizable energy (ME) values of feed ingredients could be calculated using the difference method [17]. This formula was adapted for the determination of the DE of feed ingredients. The reference diet contained 3,415 kcal/kg of ME and 1.04% of lysine on standardized ileal basis. The proximate composition of the feed ingredients and experimental diets are reported in table 2. Titanium dioxide was mixed into each of the diets at 5 g/kg of diet. Each pig received a daily feed allowance of approximately 4% of the BW of the lightest pig within each block. Daily feed intake was divided into 2 equal allotments and fed at 0700 and 1900 each day. All pigs were housed individually on slated floor pens (1.17 m × 1.17 m) in an environmentally controlled room (16 h of light and 8 h of

Table 2: Proximate analysis of corn, wheat middling, soybean meal and the experimental diets (on as-is basis, g/kg).

Item	Corn	Wheat middlings	Soybean meal	Reference diet	Reference+corn	Reference+wheat middlings
Moisture	128.1	97.0	106.2	97.5	96.6	92.2
Crude protein	84.4	159.7	485.9	193.4	193.4	181.9
Crude fat	31.2	37.0	9.6	57.5	48.0	42.8
Crude fiber	15.0	89.0	28.6	20.5	19.1	37.0
Ash	13.0	59.9	62.5	58.9	54.6	70.3
ADF[1]	23.6	126.5	69.6	ND[3]	ND	ND
NDF[2]	68.5	371.7	85.9	ND	ND	ND

[1]Acid detergent fiber
[2]Neutral detergent fiber
[3]Not determined

Table 3: Main effect of diet type and adaptation length on apparent ileal dry matter (DM) and energy (EN) digestibility and digestible energy (DE) of experimental diets in cannulated growing pigs.

Diet type	Adaptation length, days	Dry matter digestibility, %	Energy digestibility, %	Digestible energy, kcal/kg
Reference		68.4[b]	72.5[a]	3,407[a]
Reference+corn		71.1[a]	73.1[a]	3,293[b]
Reference+wheat middlings		57.4[c]	61.7[b]	2,855[c]
SEM[1]		0.521	0.612	28.44
	4	65.3	68.7	3,171
	8	65.5	68.9	3,176
	12	66.1	69.6	3,211
SEM		0.539	0.571	26.50
Probability				
Diet type		<.0001	<.0001	<.0001
Adaptation length		0.616	0.485	0.482
Diet type x adaptation length		0.557	0.524	0.534

[a-c]Values with in a column lacking a common super script letter are different ($p<0.05$). Number of replicates was 20
[1]Standard error of mean

darkness cycle). Each pen was boarded on each side with white poly-max boards to protect the pigs from injury from the cannula. Each pen was fitted with two low-pressure automatic nipple drinkers.

Sample collection, processing, and analyses

Some of the feces that were produced within the last 12 hours, prior to the start of ileal digesta collection, were collected (fecal grab) for total tract DE determination. Ileal digesta were collected between 0700 and 1900 on d 4, 8, and 12 by attaching a plastic bag to the O-ring of the cannula. To minimize microbial and enzymatic activity post collection, 10 mL of 10 % formic acid was added to each collection bag. The collection bags were changed frequently as needed or at least once within 2 h of replacing a bag and immediately placed in a -20°C freezer until processed. All the digesta collected were thawed and pooled for each pig per collection period (4 ,8, or 12), thoroughly mixed, sub sampled, and freeze-dried. Ileal digesta were freeze-dried while fecal samples were dried in a forced-air oven at 55°C for 5 days. Diets, feces, and freeze-dried ileal digesta samples were ground to pass through a 0.5 mm screen using a mill grinder (Retsch ZM 100, Retsch GmbH and Co., K.G., Haan, Germany).

Duplicate analyses were performed on diets, ileal digesta, and fecal samples. Dry matter analyses of fecal samples, ileal digesta, and diets were determined by drying the samples in a drying oven at 105°C for 16 h [18]. Diets and ileal digesta were analyzed for titanium, gross energy (GE), and N. Samples were digested as described by Myers, et al. [19] after which titanium concentration was determined by flame atomic absorption spectroscopy. Nitrogen was determined by the combustion method [18] (model FP2000, Leco Corp., St. Joseph, MI) with EDTA serving as the internal standard. The GE was determined using bomb calorimetry (Parr 6200 calorimeter, model A1290DDEB, Parr Instrument Company, Moline, IL) with benzoic acid as a calibration standard. The proximate composition of the diets, corn, soybean meal, and WM as well as the acid detergent fiber (ADF) and neutral detergent fiber (NDF) for the 3 feed ingredients were determined at the University of Missouri Experiment Station Chemical Laboratory

(Columbia, MO). Crude fat was determined by ether extraction [18]. Crude fiber, ADF, and ash contents were also determined [18]. Neutral detergent fiber (NDF) was determined using Ankom Fiber Analyzer (Ankom Technology, Macedon, NY).

Calculations

Apparent ileal and total tract dry matter, energy (EN), and N digestibility was calculated using the formula:

$$Apparent\ digestibility\ (\%) = \left[1 - \left(\frac{Ti_1}{Ti_0}\right) \times \left(\frac{N_0}{N_1}\right)\right] \times 100$$

Where Ti_1 represents the concentration of titanium in the diet (%); Ti_0 represents the concentration of titanium in the ileal digesta or fecal sample (%); N_0 represents the concentration of N (%) or GE (kcal/kg) in ileal digesta or fecal sample (%); N_1 represents the concentration of N (%) or GE (kcal/kg) in diet.

Ileal and total tract apparent DE of the diet (ADE_d) was calculated using this equation:

$$ADE_d = GE_d \times END_d$$

Where GE_d is the GE of the diet and END_d is the percent (%) ileal or total tract energy digestibility.

Apparent DE of the test ingredient (ADE_{ti}) was calculated as follows:

$$ADE_{ti} = ED_{ti} \times GE_{ti}$$

Where GE_{ti} and ED_{ti} are the GE (kcal/kg) and energy digestibility (%) of the test ingredient, respectively.

The coefficient of EN digestibility of the test ingredient (END_{ti}) was calculated using the following equation:

$$END_{ti} = \frac{\left\{END_{td} - \left[END_{rd} \times \left(1 - FC_{\frac{ti}{td}}\right)\right]\right\}}{FC_{\frac{ti}{td}}}$$

Where END_{td} is the coefficient of energy digestibility of the test diet, END_{rd} is the coefficient of energy digestibility of the reference diet, and $FC_{ti/td}$ is the fractional contribution of the test ingredient to the test diet [17].

Additionally, the effect of diets and adaptation length on hindgut fermentation was also calculated using the index method and the subtraction method.

Index method:

$$Hindgut\ fermentation_{Index\ method}\ (kcal/kg) =$$

$$\left[1 - \left(\frac{Ti_{Ileal\ digesta}}{Ti_{feces}}\right) \times \left(\frac{GE_{feces}}{GE_{Ileal\ digesta}}\right)\right] \times Ileal\ digesta\ gross\ energy$$

Subtraction method:

$$Hindgut\ fermentation\ (kcal/kg) = Total\ tract\ DE - Ileal\ DE$$

Statistical analysis

The individual pig was used as the experimental unit, and data was subjected to ANOVA using Proc Mixed procedure of SAS (SAS Inst. Inc., Cary, NC). Initial body weight was used as the blocking criterion in the experiment. To determine the effect of AL (4, 8, and 12) and diet type (reference, reference+corn, and reference+WM) on ileal and total tract DE, DM and EN digestibility, a 3 × 3 factorial arrangement of treatments was used. For the feed ingredients, a 2 (feed ingredients) × 3 (AL) factorial arrangement of treatment was used. Responses were measured on the same animal, thus a repeated statement based on multivariate analyses of contrast variables were obtained for the effects of AL on the parameters measured. Due to the sequential nature of the data on each animal, the appropriate covariance structure that fits the model was set. Thus, covariance structures were compared using goodness of fit criteria including the REML log likelihood (REML), Akaike information criterion (AIC), Schwartz Bayesian criterion (SBC), and the model with the lowest fit statistics value and the fewest number of parameters was selected. When interactions were significant, orthogonal polynomial contrast was used to determine the linear and quadratic responses of the diet type or feed ingredient and AL. When interactions were not significant, the polynomial contrast was conducted for AL, and the diet effect was compared using the Tukey's test. An α level of 0.05 was used to determine statistical significance with a P-value between 0.05 and 0.1 was taken as tendency to be significant. Values outside the mean ± 3SD were treated as outliers and were removed before statistical analyses were conducted.

Results

The interaction between AL and diet type was not significant for ileal DE, DM, and EN digestibility (Table 3). The main effect of diet type on ileal DE, DM and EN digestibility was significant with reference+WM-based diet having lower (P<0.05) values. Replacing 30% of the energy yielding components of the reference diet with corn, increased (P<0.05) ileal DM digestibility by 3.9% but decreased (P<0.05) ileal DE (Table 3). Increasing the AL to the experimental diets did not influence ileal DE, DM and EN digestibility (Table 3). The interaction between diet type and AL was not significant for total tract DE, DM and EN digestibility (Table 4). Total tract DM and EN digestibility was lower (P<0.05) for the reference+WM-based diet compared to the reference and reference+corn-based diets (Table 4). More so, replacing 30% of the energy yielding ingredients in the reference diet with corn or WM resulted in a 4.7% and 9.3 % decrease (P<0.05), respectively, in total tract DE (Table 4). Increasing the AL to the experimental diets linearly increased (P<0.05) total tract DE, DM and EN digestibility (Table 4). The effect of ingredient type and the AL on ileal and total tract EN digestibility and DE of corn and WM calculated using the difference method are summarized in tables 5 and 6, respectively. There was no interaction between ingredient type and AL on both ileal (Table 5) and total tract (Table 6) EN digestibility and DE, neither was the length of adaptation (Tables 5, 6). However, substituting WM with corn significantly lowered (P<0.05) ileal and total tract EN digestibility and DE (Tables 5, 6). The quantity of energy that disappeared from the hindgut is reported in table 7. Increasing AL to the experimental diets showed a tendency for higher (P=0.051) level of energy to disappear in the hindgut (index method; Table 7). However, the replacement of 30% of the energy yielding components of the reference diet with WM resulted in higher (P<0.05) level of energy disappearance in the hindgut compared to the average of the other two diets (736 *vs* 495 kcal/kg; Table 7). The hindgut rate of energy disappearance showed a tendency to increase (P=0.058) linearly with increasing AL (index method; Table 7).

Discussion

Accurate estimation of energy values of different feed ingredients is essential for a profitable animal feeding operation. This is important because the energy need of pigs constitutes the most expensive portion

Table 4: Main effect of diet type and adaptation length on apparent total tract dry matter (DM) and energy (EN) digestibility and digestible energy (DE) of experimental diets in cannulated growing pigs.

Diet type	Adaptation length, day	Dry matter, %	Energy digestibility, %	Digestible energy, kcal/kg	n[1]	n[2]	n[3]	SEM[4]	SEM[5]	SEM[6]
Reference		83.4[a]	83.7[a]	3,935[a]	18	18	18	0.24	0.26	12.1
Reference+corn		83.4[a]	83.1[a]	3,748[b]	18	19	19	0.24	0.26	11.8
Reference+wheat middlings		76.8[b]	77.1[b]	3,569[c]	19	20	20	0.23	0.25	11.6
	4	79.9	79.9	3,687	17	18	18	0.22	0.29	13.3
	8	81.7	81.7	3,780	20	20	20	0.20	0.21	9.8
	12	82.0	82.1	3,786	18	19	19	0.21	0.22	10.3
Probability										
Diet type		<.0001	<.0001	<.0001						
Adaptation length		<.0001	<.0001	<.0001						
Diet type x adaptation length		0.080	0.221	0.223						
Contrast	Linear	<.0001	<.0001	<.0001						
	Quadratic	0.001	0.002	0.002						

[a-c]Values within a column lacking a common superscript letter are different ($p < 0.05$)
[1]Number of replicate for dry matter digestibility
[2]Number of replicates for energy digestibility
[3]Number of replicates for digestible energy
[4]Standard error of mean for dry matter digestibility
[5]Standard error of mean for energy digestibility
[6]Standard error of mean for digestible energy

Table 5: Main effect of diet type and adaptation length on apparent ileal energy digestibility (EN_{ingr}) and digestible energy (DE_{ingr}) of corn and wheat middlings in cannulated growing pigs using the difference method.

Ingredient	Adaptation length, day	EN_{ingr},[1] %	Digestible energy kcal/kg	n[2]	n[3]	SEM[4]	SEM[5]
Corn		73.1	3,325	21	20	2.31	107.0
Wheat middlings		38.4	1,778	21	21	2.31	104.3
	4	55.6	2,523	14	14	2.58	117.6
	8	57.0	2,640	14	14	2.58	123.0
	12	54.7	2,491	14	14	2.58	117.6
Probability							
Ingredient		<.0001	<.0001				
Adaptation length		0.787	0.603				
Ingredient x adaptation length		0.368	0.530				

[1]Ingredient ileal energy digestibility
[2]Nunber or replicates for energy digestibility
[3]Number of replicates for digestible energy
[4]Standard error of mean for energy digestibility
[5]Standard error of mean for digestible energy

Table 6: Main effect of diet type and adaptation length on apparent total tract energy digestibility (EN_{ingr}) and digestible energy (DE_{ingr}) of corn and wheat middlings in cannulated growing pigs using the difference method.

Ingredient	Adaptation length, day	EN_{ingr},[1] %	Digestible energy kcal/kg	n[2]	n[3]	SEM[4]	SEM[5]
Corn		81.2	3,668	19	19	1.00	45.6
Wheat middlings		62.0	2,864	20	20	0.98	44.7
	4	70.3	3,208	12	12	1.46	66.4
	8	71.9	3,278	14	14	0.89	40.2
	12	72.6	3,312	13	13	1.05	48.0
Probability							
Ingredient		<.0001	<.0001				
Adaptation length		0.507	0.489				
Ingredient x adaptation length		0.779	0.723				

[1]Ingredient total tract energy digestibility
[2]Number of replicates for energy digestibility
[3]Number of replicates for digestible energy
[4]Standard error of mean for energy digestibility
[5]Standard error of mean for digestible energy

Table 7: Main effect of diet and adaptation length on hindgut energy disappearance (kcal/kg) in cannulated growing pigs

	Hindgut energy disappearance, kcal/kg						
Diet type	Adaptation length, day	Index method[1]	Subtraction[2]	n[3]	n[4]	SEM[5]	SEM[6]
Reference		1,643	521[b]	19	19	63.4	33.5
Reference+corn		1,590	468[b]	19	19	63.4	33.5
Reference+wheat middlings		1,695	736[a]	21	21	59.8	31.7
	4	1,511	540	19	19	64.4	34.4
	8	1,727	604	21	21	60.9	29.6
	12	1,690	582	19	19	64.4	34.4
Probability							
Diet type		0.498	<.0001				
Adaptation length		0.051	0.366				
Diet type x adaptation length		0.779	0.710				
Orthogonal contrast	Linear	0.058					
	Quadratic	0.109					

[a-b]Values within a column lacking a common superscript letter are different ($p < 0.05$)
[1]Index method was calculated as: [1-(Ti in ileal digesta/Ti in feces) × (energy in feces/energy in ileal digesta)] × GE of ileal digesta
[2]Calculated as: Total tract digestible energy–Ileal digestible energy
[3]Number of replicates for index method
[4]Number of replicates for subtraction method
[5]Standard error of mean for index method
[6]Standard error of mean for subtraction method

of total feed cost, which is estimated to be about 70% of the cost of raising a pig to market weight. With increasing use of alternative sources of feed ingredients in swine diets, it is important to have accurate information on the DE contents of each feed ingredient. Unlike corn (yellow dent) whose DE values have been copiously reported, the available information on the DE values of WM, as reported in the Swine NRC [16], is few. The proportion of crude fiber to starch in WM is high compared to corn [16], and as a result, the replacement of a portion of the energy yielding components of the corn-SBM-based reference diet with WM will result in higher level of crude fiber (as well as NDF and ADF) and lower level of starch. Furthermore, we are interested in evaluating the effect of replacing 30% of the energy yielding components (corn, SBM, and soy oil) in the corn-SBM-based (reference) diet with corn to evaluate the effects of an increasing the level of starch in the reference+corn-based diet on ileal and total tract EN and DE values. Based on this, the objective of this study was to determine the effects of AL and diet type on apparent ileal and total tract DE values of complete diets, corn, and WM in cannulated growing pigs. Secondly, the influence of feed ingredients (corn and WM) on the amount of DE lost in the hindgut was determined using the index and subtraction methods. The proximal nutrient composition of the corn, WM, and SBM used in the current study is similar to values reported in Swine NRC [19]. All pigs were healthy throughout the duration of the study.

One of the important steps in any digestibility study is to ensure that animals are adequately adapted to the test diets [20]. This period of adaptation is important as it allows the pig to get used to the quality (palatability) and quantity of feed that is being offered, usually in the morning and evening. Furthermore, it allows the remnants of the pre-experimental diets in the GIT to be completely voided, and in some cases, ensuring that the microbiota within the GIT have adjusted to the new diet in terms of stability and establishment of the microbial population within the gut. Any of these factors could affect the DE of a diet or feed ingredient. Adaptation lengths ranging from 7 to 24 days have been reported in the literature [21,22].

In the current study, replacing the energy yielding components of the reference diet with corn resulted in a 3.9% increase in ileal DM digestibility however, ileal DE value decreased by 3.3% (3,293 *vs* 3,407 kcal/kg) compared to the reference diet. This decrease in DE, despite similar energy digestibility, is as a result of a decrease in the diet's GE value with 30% corn replacement of the energy yielding portion of the reference diet. Diet GE decreased by about 4.5% from 4,176 to 3,986 kcal/kg (on as-is basis). Apparent ileal DM and EN digestibility of the reference+WM-based diet decreased by 16 and 15%, respectively, while DE decreased by 16% when compared to that of the reference diet.

The relatively lower ileal and total tract EN and DE of the diet containing WM in the current study is similar to previously reported values. This has been attributed to the increased level of the anti nutritive dietary insoluble fiber [23]. A lower ileal and total tract GE digestibility in a corn-SBM-WM-based diet (WM replaced 25% of corn and SBM in the basal diet) compared to corn-based diet has been reported [13]. This difference between the corn-based and corn-SBM-WM-based diets in DM, N, and EN digestibility was more pronounced in the ileal (EN digestibility: 81.5 *vs* 43.6%) compared to total tract (EN digestibility: 83.5 *vs* 72.2%) values for the pigs in the same study [13]. In the current study, the corn-SBM-based reference diet had a higher ileal DM (11.0%-points) and EN (10.8%-points) digestibility, as well as DE (552 kcal/kg) compared to the corn-SBM-WM-based diet. For the total tract data, the respective values were 6.6% (DM), 6.6% (EN) digestibility, and 366 kcal/kg (DE). High level of fiber has been reported to always result in a decrease of ileal and total tract digestibility values [13,24,25]. Apparent ileal DM and EN digestibility obtained from the current study is similar to what has been previously reported [22]. They also reported similar trends for ileal and total tract DM and EN digestibility in corn-SBM-based basal diet compared to corn-SBM-WM based diets. The apparent total tract EN digestibility value of the reference+corn (83.1%) and reference+WM (77.1%) based diets were similar to 85.8 and 78.9%, respectively, reported for corn and WM-based-diets [21] where pigs were fed the experimental diets for 24 days. Likewise, total tract DE values reported in the same study [21] for growing pigs for corn (3,676 kcal/kg) and WM (3,408 kcal/kg) containing diets are similar to what was obtained in the current study (3,935 kcal/kg for reference+corn-based and 3,569 kcal/kg for reference+WM-based diets). According to the data previously reported for growing pigs [22], the apparent ileal EN digestibility values of corn-SBM-WM based diet after 8 days of adaptation, was about 5% higher (65.5 *vs* 62.0%) than the values in the current study after 8 days of adaptation to the reference+WM-based diet. In the same study [22], the total tract DE of the corn-SBM-WM-based diet reported was 3,218 kcal/kg which is lower than the value obtained in the current study (3,569 kcal/kg). This could be attributed to the higher EN digestibility values (77.1 *vs* 67.6%). In general, the replacement of the energy yielding components of the reference diet reduced the ability of the pigs to optimally utilize the energy from WM. This result is consistent with what has previously been reported [14, 26-27]. In comparison to what has been reported [13], where ileal EN digestibility values of corn and WM in the DLY breed of pigs were 81.5 and 40.5, respectively, a decrease of 50%, the current study observed a decrease of 48% (corn=73.1 and WM=38.4%). This difference can be attributed to an increase in the fiber level of WM compared to corn. Consequently, the high fiber level in WM resulted in a significantly lower ileal DE of WM (by about 47%) compared to corn in the current study. The apparent total tract EN digestibility of WM was also lower to that of corn in the current study, which is similar to what has been previously reported [13]. However, the difference in the total tract EN digestibility between corn and WM was much lower (24%) compared to what was obtained at the ileal level (47%). Interestingly, the difference between apparent ileal and total tract EN digestibility of corn in the current study and the results by Zhao, et al. [13] was in the single digit (<10% points; 81.2 *vs* 73.1%) compared to WM in the current study where the difference was in the double digits (24%-points; 62.0 *vs* 38.4%, respectively). This could be attributed to the increased level of activities of the hindgut microbes. Wheat middlings is high in crude fiber, especially soluble fiber, which is capable of serving as a good source of nutrients to the microbes. Hence, the higher level of activities of these microbes would have led to the double-digit increase in total tract EN digestibility. The total tract DE values of corn (3,668 kcal/kg) and WM (2,864 kcal/kg) from the current study are similar to what has been previously reported [16] for yellow dent corn (3,451 kcal/kg) and WM (3,075 kcal/kg).

The disappearance of EN in the hindgut was calculated using both the index marker and subtraction methods (total tract DE-ileal DE). First, the disappearance of dietary EN in the hindgut of the pigs in the current study was not significantly influenced by the length of adaptation to the diets (index method showed a tendency to increase with AL). Furthermore, the percentage of the GE that is lost in the hindgut (determined by the index method) is comparable to what has been previously reported [28]. They [28] reported a 36% (low resistant starch corn) and 49% (high resistant corn) energy loss due to fermentation in the hindgut compared to 40, 38, and 41% for the reference diet, reference+corn, and reference+WM-based diets, respectively (current study). However, a tendency for increasing level of EN disappearance in the hindgut with increasing length of adaptation was observed for the index method. The proportion of EN lost to fermentation in the hindgut increased from 41 to 46% from 4 to 8 days of adaptation while it remained essentially the same from day 8 to 12 (46 vs. 45%). This indicates that beyond 8 days of adaptation, the hindgut microbial population would have stabilized, hence no increase in the rate of energy disappearance as a result of fermentation in the hindgut. Furthermore, the inclusion of WM in the diet resulted in an increased level of EN disappearance by about 49% compared to the average of the reference and reference-corn-based diets (with the subtraction method). These two methods gave different average values of energy that was lost in the hindgut. For example, the average DE that was lost in the hindgut was 1,634 and 575 kcal/kg for the index and subtraction methods, respectively. Going by the results that was obtained for the diet ileal and total tract DE, the subtraction method seems to present a better picture of the proportion of energy that was lost in the hindgut. Furthermore, results using the subtraction method in the current study is similar to what has been reported for corn-SBM-WM-based diet (687 kcal/kg) [22] using the subtraction method.

Conclusion

Data from this study confirmed the anti nutritive effect of the high fiber contents of WM in pigs' diet. Although apparent DE values of both the corn and WM increased from the terminal ileum to the end of the large intestine (ileal *vs* fecal samples), the increase for WM was much higher (61 *vs* 10%). Finally, increasing the AL beyond 8 days did not yield any further increase in DE value of the diet and feed ingredients evaluated in this study.

Acknowledgement

This work is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, Hatch-Multistate Program (Project 2351467000) under Accession number 1005963.

References

1. Patience JF (2009) Energy in Swine Nutrition. Animal Industry Report, digital Press, lowa state university.
2. Kumar V, Sinha AK, Makkar HP, de Boeck G, Becker K (2012) Dietary roles of non-starch polysaccharides in human nutrition: a review. Crit Rev Food Sci Nutr 52: 899-935.
3. Bakker GCM, Dekker RA, Jongbloed R, Jongbloed AW (1998) Non-starch polysaccharides in pig feeding. Vet Q 20: 59-64.
4. Serena A, Jørgensen H, Bach Knudsen KE (2008) Digestion of carbohydrates and utilization of energy in sows fed diets with contrasting levels and physicochemical properties of dietary fiber. J Anim Sci 86: 2208-2216.
5. Noblet J, Le Goff G (2001) Effect of dietary fibre on the energy value of feeds for pigs. Anim Feed Sci Tech 90: 35-52.
6. Wenk C (2001) The role of dietary fibre in the digestive physiology of the pig. Anim Feed Sci Tech 90: 21-33.
7. Noblet J, Perez JM (1993) Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J Anim Sci 71: 3389-3398.
8. Wenk C, Messikommer R, Bee G (1998) Effect of lignin from different origins in combination with carbohydrases in pig diets on digestion processes. Anim Sci Supply 76: 179.
9. Moeser AJ, Van Kempen T (2002) Dietary fiber level and enzyme inclusion affect nutrient digestibility and excreta characteristics in grower pigs. J Sci Food Agric 82: 1606-1613.
10. Dégen L, Halas V, Tossenberger J, Szabó C, Babinszky L (2009) The impact of dietary fiberand fat levels on total tract digestibility of energy and nutrients in growing-finishing pigs and itsconsequence for diet formulation. Acta Agric Scand Sect A Anim Sci 59: 150-160.
11. Noblet J, Bach Knudsen KE (1991) Comparative digestibility of wheat, maize, and sugarbeet pulp non-starch polysaccharides in adult sows and growing pigs. In Laplace JP, Fevrier C, Barbeau A (eds) Proceedings of the Seventh International Symposium on Digestive Physiologyin Pigs. EAAP publication no 88: 571-574.
12. Wenk C (1992) Enzymes in the nutrition of monogastric farm animals. In: Lyons TP (ed). Proceedings of Alltech's 8th Annual Symposium. Alltech Technical Publications, Nicholasville, USA 205-218.
13. Zhao JB, Zhang G, Liu L, Chen YQ, Jin AM (2018) Comparative nutrient digestibility in different ingredients fed to Duroc × Landrace × Yorkshire and Duroc × Berkshire × Jiaxing growing barrows. Livestock Sci 211: 1-7.
14. Huang C, Zhang S, Stein HH, Zhao J, Li D (2017) Effect of inclusion level and adaptation duration on digestible energy and nutrient digestibility in palm kernel meal fed to growing-finishing pigs. AJAS 31: 395-402.
15. Dilger RN, Sands JS, Ragland D, Adeola O (2004) Digestibility of nitrogen and amino acids in soybean meal with added soyhulls. J Anim Sci 82: 715-724.
16. National Research Council (2012) Nutrient Requirements of Swine: Eleventh Revised Edition Washington, DC: The National Academies Press.
17. Olukosi OA, Adedokun SA, Agboola JO (2017) Species-dependent response to the influence of adaptation length during assay for metabolisable energy of cereal grains employing the difference method. Anim Feed Sci Tech 231: 111-118.
18. AOAC (2006) Official Methods of Analysis of AOAC International. 18th edition. Assoc Off Anal Chem, Arlington, VA, USA.
19. Myers WD, Ludden PA, Nayigihugu V, Hess BW (2004) Technical note: a procedure for the preparation and quantitative analysis of samples for titanium dioxide. J Anim Sci 82: 179-183.
20. Adeola O (2001) Digestion and balance techniques in pigs. In: Lewis AJ, Southern LL (eds) Swine Nutrition. 2nd edition, CRC Press LLC, Boca Raton, FL USA, 903-916.
21. Lowell JE, Liu Y, Stein HH (2015) Comparative digestibility of energy and nutrients in diets fed to sows and growing pigs. Archives Anim Nutr 69: 79-97.
22. Jaworski NW, Stein HH (2017) Disappearance of nutrients and energy in the stomach and small intestine, cecum, and colon of pigs fed corn-soybean meal diets containing distillers dried grains with solubles, wheat middlings, or soybean hulls. J Anim Sci 95: 727-739.
23. Bach Knudsen KE (2011) Triennial Growth Symposium: effects of polymeric carbohydrates on growth and development in pigs. J Anim Sci 89: 1965-80.
24. Wu F, Johnston LJ, Urriola PE, Hilbrands AM, Shurson GC (2016) Effects of feeding diets containing distillers' dried grains with solubles and wheat middlings with equal predicted dietary net energy on growth performance and carcass composition of growing-finishing pigs. J Anim Sci 94: 144-154.
25. Salyer JA, DeRouchey JM, Tokach MD, Dritz SS, Goodband RD, et al. (2012) Effects of dietary wheat middlings, distillers dried grains with solubles, and choice white grease on growth performance, carcass characteristics, and carcass fat quality of finishing pigs. J Anim Sci 90: 2620-2630.
26. Wilfart A, Montagne L, Simmins PH, van Milgen J, Noblet J (2007) Sites of nutrient digestion in growing pigs: effect of dietary fiber. J Anim Sci 85: 976-983.
27. Huang Q, Su YB, Li DF, Liu L, Huang CF, et al. (2015) Effects of inclusion levels of wheat bran and body weight on ileal and fecal digestibility in growing pigs. Asian-Australas J Anim Sci 28: 847-854.
28. Lu H, Yan H, Almeida VV, Adeola O, Ajuwon KM (2016) Effects of dietary resistant starch content on nutrient and energy digestibility and fecal metabolomic profile in growing pigs. J Anim Sci 94: 364-368.