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

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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...
poly saccharides often called non-starch polysaccharides (NSP). The majority of NSP is often comprised of cellulose, pectins, β-glucans, pentosans, heteroxylans, and xylol gluc [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 preocc evolution 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 digestion. 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-celal colon 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 x 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.

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 fulfill 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 standard 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. 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. 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. 

![Table 1: Composition of the experimental diets fed to the growing pigs (on as-fed basis).](image-url)
darkness cycle). Each pen was boarded on each side with white poly- 
mix 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 tran 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 day 
s.

### 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                      |
| ADF¹              | 23.6     | 126.5           | 69.6         | ND¹            | ND             | ND                        |
| NDF²              | 68.5     | 371.7           | 85.9         | ND             | ND             | ND                        |

¹Acid detergent fiber  
²Neutral detergent fiber  
³Not 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⁺                      | 72.5⁺                   | 3,407⁺                     |
| Reference+corn           |                         | 71.1⁺                      | 73.1⁺                   | 3,293⁺                     |
| Reference+wheat middlings|                         | 57.4⁺                      | 61.7⁺                   | 2,855⁺                     |
| SEM¹                    |                         | 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                   |

¹Values with in a column lacking a common super script letter are different (p<0.05). Number of replicates was 20  
²Standard error of mean
Calculations

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

\[
\text{Apparent digestibility} = 1 - \left( \frac{\text{TIN}}{\text{FDI}} \right) \times \left( \frac{\text{N}_{\text{in}}}{\text{N}_{\text{out}}} \right)
\]

Where Ti represents the concentration of titanium in the diet (%); TIN represents the concentration of N (%) or GE (kcal/kg) in ileal digesta or fecal sample (%); N in 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:

\[
\text{ADE d} = \text{GE d} \times \text{END d}
\]

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 t) was calculated as follows:

\[
\text{ADE t} = \text{ED t} \times \text{GE t}
\]

Where GE t and ED t are the GE (kcal/kg) and energy digestibility (%) of the test ingredient, respectively.

The coefficient of EN digestibility of the test ingredient (END t) was calculated using the following equation:

\[
\text{END t} = \left( \frac{\text{EN dt} - \left( \text{EN d} \times \left( 1 - \frac{\text{GE t}}{\text{GE d}} \right) \right)}{\text{FC t}} \right)
\]

Where END dt is the coefficient of energy digestibility of the test diet, EN d is the coefficient of energy digestibility of the reference diet, and FC t 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:

\[
\text{Hindgut fermentation}_{\text{index method}} \text{(kcal/kg)} = 
\]

\[\left( 1 - \left( \frac{\text{Fc \text{in}}}{\text{Fc \text{out}}} \right) \right) \times \left( \frac{\text{GE \text{in}}}{\text{GE \text{out}}} \right) \times \text{Ileal digesta gross energy}
\]

Subtraction method:

\[
\text{Hindgut fermentation} \text{(kcal/kg)} = \text{Total tract DE} - \text{Ileal DE}
\]

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

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### 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 | n² | n³ | SEM⁴ | SEM⁵ | SEM⁶ |
|-------------------------|------------------------|---------------|-------------------------|----------------------------|----|----|------|------|------|
| Reference               | 83.4⁺                  | 83.7⁺         | 3,935⁺                  | 18                         | 18 | 18 | 0.24 | 0.26 | 12.1 |
| Reference+corn          | 83.4⁺                  | 83.1⁺         | 3,748⁺                  | 18                         | 19 | 19 | 0.24 | 0.26 | 11.8 |
| Reference+wheat middlings | 76.8⁺                 | 77.1⁺         | 3,569⁺                  | 19                         | 20 | 20 | 0.23 | 0.25 | 11.6 |
|                         | 4                      | 79.9          | 79.9                    | 17                         | 18 | 18 | 0.22 | 0.29 | 13.3 |
|                         | 8                      | 81.7          | 81.7                    | 20                         | 20 | 20 | 0.20 | 0.21 | 9.8  |
|                         | 12                     | 82.0          | 82.1                    | 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     |
|                        |                         | Quadratic| 0.001      | 0.002      |

*Values within a column lacking a common superscript letter are different (p < 0.05)

¹Number of replicates for dry matter digestibility
²Number of replicates for energy digestibility
³Number of replicates for digestible energy
⁴Standard error of mean for dry matter digestibility
⁵Standard error of mean for energy digestibility
⁶Standard 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 | n² | n³ | SEM⁴ | SEM⁵ |
|----------------------|------------------------|-------------|---------------------------|----|----|------|------|
| 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      |

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

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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,

| Ingredient       | Adaptation length, day | ENAAP 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  | 1.46 | 66.4  |
|                  | 8                      | 71.9      | 3,278                     | 14  | 0.89 | 40.2  |
|                  | 12                     | 72.6      | 3,312                     | 13  | 1.05 | 48.0  |

Probability

| Ingredient                                | Adaptation length, day | <.0001 | <.0001 |
|-------------------------------------------|------------------------|--------|--------|
| Adaptation length                         | 0.507                  | 0.489  |
| Ingredient x adaptation length            | 0.779                  | 0.723  |

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

| Diet type                        | Adaptation length, day | Index method 1 | Subtraction 2 | n 3 | n 4 | SEM 5 | SEM 6 |
|----------------------------------|------------------------|----------------|---------------|-----|-----|-------|-------|
| Reference                        | 1,643                  | 521 3          |               | 19  | 19  | 63.4  | 33.5  |
| Reference+corn                   | 1,590                  | 468 3          |               | 19  | 19  | 63.4  | 33.5  |
| Reference+wheat middlings        | 1,695                  | 736 3          |               | 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 | 0.366  |
|----------------------------------|------------------------|--------|--------|
| Adaptation length                | 0.051                  | 0.779  | 0.710  |
| Diet type x adaptation length    | 0.058                  |        | 0.109  |

2 3 4 5 6

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

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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.

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