EFFECTS OF DIETARY FIBER OF YOUNG ADULT GENETICALLY LEAN, OBESE AND CONTEMPORARY PIGS: RATE OF PASSAGE, DIGESTIBILITY AND MICROBIOLOGICAL DATA

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ABSTRACT

Twenty-one genetically lean, obese or contemporary slaughter weight castrated male pigs (6 mo old; seven of each genotype) were assigned to individual tether stalls and fed either a control diet (low fiber) or a diet containing 80% alfalfa meal (high fiber) at 1.50% of initial body weight for 71 d (1.75% for d 1 to 4). Apparent dry matter digestibility of the diets was estimated by determining acid insoluble ash in fecal samples. Fecal cellulolytic bacteria and total viable bacteria were enumerated at d 0, 14, 35, 49 and 70. Fecal inocula were used to determine 48-h in vitro digestibility of alfalfa meal fractions on the same days. Digesta rate of passage was determined by feeding a pulse dose of chromium-mordanted alfalfa fiber to the pigs fed the high-fiber diet. In vivo digestibility of both diets was less for the obese pigs than for the lean or contemporary genotypes. In vitro digestibility of alfalfa fiber fractions was not different between the genotypes fed either diet. When the high-fiber diet was fed, in vitro digestibility increased for all genotypes from d 0 to d 14, but not thereafter. The numbers of cellulolytic bacteria for all three genotypes were greater when pigs were fed the high-fiber diet (23.0 X 10^8, 51.6 X 10^8, 37.2 X 10^8 per gram fecal dry weight; obese, lean and contemporary, respectively) compared to the low-fiber diet (3.0 X 10^8, 3.2 X 10^8, 3.4 X 10^8, respectively). There was a trend for lower numbers of cellulolytic bacteria in the fecal samples of obese pigs fed the high-fiber diet than of the lean or contemporary pigs. Digesta rate of passage was faster for the obese pigs. The fact that the rate of passage is faster explains the lower in vivo fiber digestibility by the obese pigs compared with that by the other genotypes.

(Key Words: Pigs, Genotypes, Fiber, Digestibility, Bacteria.)

Introduction

Microbial degradation of fiber in the cecum and colon of pigs may generate up to 30% of the animal's energy requirement (Rerat et al., 1987). This figure may even be higher for adult animals because sows can maintain normal reproductive performance when fed diets containing 96% to 100% alfalfa meal (Danielson and Noonan, 1975; Pollman et al., 1981; Calvert et al., 1985), and the numbers of cellulolytic bacteria in fecal samples of adult pigs are larger than those in growing pigs (Varel and Pond, 1985). Some of the predominant fiber-degrading bacterial species found in the rumen have been isolated from the intestinal tract of pigs in numbers comparable to those seen in the rumen (Varel et al., 1984a, 1987). This provides an explanation of how significant quantities of plant cell walls can be degraded in the pigs large intestine.

A preliminary study suggested that genetic differences may exist between growing-finishing lean and obese pigs in their cellulolytic microflora, and thus in their ability to adapt to high-fiber diets (Varel et al., 1982). Pekas et al. (1983) and Pond et al. (1987) have shown that the gastrointestinal tracts of lean pigs are heavier than those of obese pigs when a high-fiber diet is fed. However, a study examining the digestibility of fiber in obese pigs has not been conducted.

The objectives of the present study were to determine the effects of including 80% alfalfa meal (high fiber) in a diet fed to young adult castrated male pigs of three genetic backgrounds. In this paper, we report the digestibility of the
diet constituents, rate of passage of feed residues through the gastrointestinal tract and cellulolytic populations in the lower intestinal tract. Body weight, carcass and organ weights and digesta volume and weight are reported elsewhere (Pond et al., 1987).

**Materials and Methods**

Twenty-one genetically lean, obese and contemporary crossbred young adult (6 mo old) castrated male pigs were fed either an 80% alfalfa meal diet (high fiber) or a control diet (low fiber) for 71 d. The animals, diets and housing conditions used in this study are described elsewhere (Pond et al., 1987). Four pigs from each genotype were fed the high-fiber diet, and three of each genotype were fed the control diet. All pigs had been fed the control diet prior to the start of the experiment. Antimicrobial agents were not fed prior to or during the experimental period. Rectal samples of fecal material were collected in air-tight plastic bottles at d 0, 14, 35 and 49 from the four pigs in each group fed the high-fiber diet and from all pigs 24 h before slaughter (d 71). These fecal samples were processed within 15 min of collection and were analyzed for numbers of cellulolytic bacteria and in vitro digestibility of alfalfa meal fractions.

Total viable bacteria were enumerated (four replicate tubes from each of the $10^{-6}$ and $10^{-9}$ fecal dilutions), and cellulolytic bacteria were enumerated by inoculating cellulose agar roll-tubes (three replicate tubes from each of the $10^{-6}$, $10^{-7}$ and $10^{-8}$ fecal dilutions) as previously published (Varel and Pond, 1985). Fifty-milliliter plastic centrifuge tubes with screw caps were used for the in vitro fermentations. Six milliliters from 1:10 anaerobic dilutions of respective fecal samples, which were strained through two layers of cheesecloth, were used as inocula for the in vitro fermentations. Six milliliters from 1:10 anaerobic dilutions of respective fecal samples, which were strained through two layers of cheesecloth, were used as inocula for the in vitro fermentations. Composition of the fermentation media used to determine in vitro digestibility of alfalfa meal fractions after 48 h incubation at 37°C were (per 30 ml): anaerobic buffer (Betain et al., 1977), 24 ml; and alfalfa meal, .5 g. The tubes were inverted 10 times at 0800 and 1600 daily. The in vitro fermentations were terminated by centrifugation at 2500 x g for 20 min, and residual pellets were analyzed for fiber content (cell walls, hemicellulose, cellulose, lignin) by the sequential detergent method of Van Soest and Robertson (1980). If a particular treatment of the in vitro fermentations could not be centrifuged immediately, tubes were stored at 0°C for up to 48 h and then centrifuged. Total alfalfa cell walls were determined by neutral detergent extraction. Hemicellulose and cellulose were calculated by weight differences as follows: neutral detergent fiber minus acid detergent fiber equaled hemicellulose, and acid detergent fiber minus acid detergent lignin (72% H$_2$SO$_4$) equaled cellulose. All in vitro fermentations were run in triplicate. Digestibility was calculated as the disappearance of the component during fermentation relative to its initial concentration. Correction was made for addition of the components in the inoculum that were not significant.

On d 56, a pulse dose of chromium-mordant cell walls (Uden et al., 1980) from alfalfa was mixed with the daily rations (2% of intake) for all pigs fed the high-fiber diet to examine rate of passage. After feeding the chromium, fecal samples (20 per pig) were collected every 4 h for 48 h, every 6 h for the next 24 h, and finally, every 12 h for the next 48 h. Chromium concentration in the feces was determined by atomic absorption spectrophotometry. The fecal samples taken at 0800 on d 57, 58 and 59 were composited and used to determine acid insoluble ash content (Van Keulen and Young, 1977) for calculation of in vivo digestibility of the diets. Fecal samples also were collected on d 57, 58 and 59 from the pigs fed the low-fiber diet for estimation of in vivo digestibility.

Rate of passage parameters were estimated for the animals fed the high-fiber diet by fitting the one compartment model with time delay of Ellis et al. (1984) to the chromium excretion data. The age-dependent rate parameter for compartmental turnover ($\lambda$) and residence time due to displacement flow (time delay between pulse dosing and first appearance of marker in feces; $T$) were estimated using the nonlinear (NLIN) procedure of SAS (1985) by the Marquardt Method. Mean residence time (MRT) of the marker was calculated as:

$$\text{MRT} = \frac{2}{\lambda} + T$$

All data were treated by least-squares analysis of variance (SAS, 1985). Number of cellulolytic bacteria and digestibility data were analyzed as a split-plot, with time as a subplot.

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unit and diet and genotype as main effects, in a
2 x 3 factorial. All possible interactions were
considered. Orthogonal contrasts were used to
test for linear and quadratic effects of time on
the high-fiber diet. The in vivo digestibility data
were analyzed as a 2 x 3 factorial with diet,
genotype and diet x genotype tested. The F-protected least significant differences method
was employed to compare means.

Results

In vivo digestibility of dry matter, crude
protein, cell walls, hemicellulose, cellulose and
gross energy across both the low-fiber and
high-fiber diets was less (P < .05) for the obese
pigs than for the lean or contemporary geno-
types (Table 1). As expected, digestibility of
the high-fiber diet was less (P < .05) than
digestibility of the low-fiber diet for all three
genotypes. No genotype x diet interactions
were observed (P > .05). Inoculum dry matter
for 48-h in vitro digestibility studies was higher
(P < .05) for all pigs fed the low-fiber diet than
for those fed the high-fiber diet (Table 2).
Regardless of this, in vitro digestibility of
alfalfa meal cell walls, hemicellulose and
cellulose was not different among the geno-
types or diets, with the exception of a lower
digestibility (P < .05) of cell walls by the
contemporary pigs on the low-fiber diet.

The total numbers of viable bacteria that
were cultured from fecal samples were greater
(P < .05) from obese pigs fed either the high-
fiber or low-fiber diet than from lean or contem-
porary pigs fed these diets (Table 3). There was
a trend for lower numbers of cellulolytic bacteria from fecal samples of the obese pigs
fed the high-fiber diet. The numbers of cel-
ulolytic bacteria for all three swine genotypes were
greater (P < .05) when they were fed the low-
fiber diet than when they consumed the low-
fiber diet. The number of cellulolytic bacteria
as a percentage of the viable count was less than
1% for the pigs fed the low-fiber diet and less
than 7% for pigs fed the high-fiber diet.

Table 4 shows data on cellulolytic bacteria
and in vitro digestibility of alfalfa fiber frac-
tions in relation to sampling time for pigs fed
the high-fiber diet. The number of cellulolytic
bacteria appeared greater than the control (day
0) after the high-fiber diet was fed. This corre-
sponded to a quadratic increase (P < .05) in
digestibility of the alfalfa meal fiber fractions.
The major changes occurred within 14 d, with
little change thereafter. There was no genotype

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Dry matter-b</th>
<th>Crude protein</th>
<th>Cell wall</th>
<th>Hemi-cellulose</th>
<th>Cellulose</th>
<th>Gross energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>45.9</td>
<td>84.5</td>
<td>53.1</td>
<td>62.3</td>
<td>27.4</td>
<td>80.8</td>
</tr>
<tr>
<td>High</td>
<td>53.4</td>
<td>88.2</td>
<td>59.5</td>
<td>49.8</td>
<td>35.2</td>
<td>82.6</td>
</tr>
<tr>
<td>Contemporary</td>
<td>50.2</td>
<td>88.1</td>
<td>58.5</td>
<td>47.8</td>
<td>36.1</td>
<td>82.6</td>
</tr>
</tbody>
</table>

480% Alfalfa meal diet (high), corn-soy diet (low).
5Digestibility of the corn-soy diet was greater (P < .05) than that of the 80% alfalfa meal diet for all genotypes.
6The obese pigs had a lower (P < .05) digestibility of all diet components for both diets than the lean or contemporary genotypes.
7There were no genotype x diet interactions (P > .05).
TABLE 2. COMPARISON OF FECAL INOCULUM DRY MATTER AND 48-H IN VITRO DIGESTIBILITY OF ALFALFA MEAL FRACTIONS FROM THREE PIG GENOTYPES

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Inoculum dry matter, %ab</th>
<th>In vitro digestibility, %</th>
<th>Cell wallsac</th>
<th>Hemicellulosea</th>
<th>Cellulosea</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Obese</td>
<td>2.7</td>
<td>6.4</td>
<td>22.1</td>
<td>21.7</td>
<td>32.0</td>
</tr>
<tr>
<td>Lean</td>
<td>2.7</td>
<td>7.1</td>
<td>23.0</td>
<td>24.7</td>
<td>34.7</td>
</tr>
<tr>
<td>Contemporary</td>
<td>2.3</td>
<td>7.0</td>
<td>23.8</td>
<td>18.1</td>
<td>33.9</td>
</tr>
<tr>
<td>SE</td>
<td>.4</td>
<td>1.2</td>
<td>2.2</td>
<td>2.2</td>
<td></td>
</tr>
</tbody>
</table>

a80% Alfalfa meal diet (high); corn-soy diet (low).

bThe 80% alfalfa meal diet had a lower (P < .05) inoculum dry matter content for all genotypes.

cCell wall digestibility was different (P < .05) for the contemporary genotype fed different diets, but not for the other genotypes.

or diet × genotype interaction for any of the fiber fractions (P > .05).

The estimates of λ did not differ (P > .05) among the swine genotypes. The obese swine did have a shorter (P < .05) residence time due to displacement flow (T) than the other two genotypes. This effect of T was also responsible for a shorter (P < .05) MRT for the obese genotype.

Discussion

When Pond et al. (1986) fit a two-compartment model (Ellis et al., 1984) to digesta passage data for swine, they found equal turnover rates for both compartments. Holzgraefe et al. (1985) had reported a similar result for another two-compartment model (Ellis et al., 1979). We also found similar turnover rates when the Ellis et al. (1984) two-compartment model was fit to the current data set (results not shown). Such equivalent turnover rate estimates suggest that the two-compartment models as currently formulated are inappropriate for estimating rate of passage in swine (Pond et al., 1986). Therefore, only results from the single-compartment model will be discussed.

Previous reported values for MRT of swine fed alfalfa have ranged from 36 to 55 h (Ehle et al., 1982; Holzgraefe et al., 1985; Pond et al., 1986). The overall MRT for animals in this study was well within this range (40.1 h). No other estimates of digesta passage rate are

TABLE 3. COMPARISON OF TOTAL VIABLE BACTERIA AND CELLULOZYTIC BACTERIA FROM FECAL SAMPLES OF THREE PIG GENOTYPES

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Total viable bacteria (1010)ab</th>
<th>Cellulolytic bacteria (104)ac</th>
<th>Cellulolytic/ viable, %c</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Obese</td>
<td>10.5</td>
<td>11.7</td>
<td>23.0</td>
</tr>
<tr>
<td>Lean</td>
<td>7.5</td>
<td>7.6</td>
<td>51.6</td>
</tr>
<tr>
<td>Contemporary</td>
<td>7.4</td>
<td>7.3</td>
<td>37.2</td>
</tr>
<tr>
<td>SE</td>
<td>1.4</td>
<td>8.7</td>
<td>5.2</td>
</tr>
</tbody>
</table>

aPer gram dry weight of feces.

bAcross both diets, the obese pigs had higher bacterial counts (P < .05).

cNumber of cellulolytic bacteria were different (P < .05) between high-fiber and low-fiber diets across all genotypes.

dThere were no genotype × diet interactions (P > .05).
DIGESTIBILITY OF FIBER BY YOUNG ADULT PIGS

TABLE 4. COMPARISON OF CELLULOLYTIC BACTERIA COUNTS AND 48-H IN VITRO DIGESTIBILITY OF ALFALFA FIBER FRACTIONS INOCULATED WITH FECAL SAMPLES FROM THREE PIG GENOTYPES FED 80% ALFALFA MEAL

<table>
<thead>
<tr>
<th>Time on diet, d</th>
<th>Cellulolytic bacteria(^b), 10(^8)/g dry wt</th>
<th>Digestibility of alfalfa meal (g/g fecal dry matter added)(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cellulose</td>
</tr>
<tr>
<td>0</td>
<td>.35</td>
<td>.40</td>
</tr>
<tr>
<td>14</td>
<td>1.51</td>
<td>1.55</td>
</tr>
<tr>
<td>35</td>
<td>1.80</td>
<td>1.74</td>
</tr>
<tr>
<td>49</td>
<td>1.70</td>
<td>1.83</td>
</tr>
<tr>
<td>70</td>
<td>1.62</td>
<td>1.70</td>
</tr>
<tr>
<td>SE</td>
<td>.27</td>
<td>.28</td>
</tr>
</tbody>
</table>

\(^a\)Significant (P < .05) quadratic effect of time.

\(^b\)Significant (P < .05) linear effect of time.

Available for the three swine genotypes compared in this report, but the observation that the obese swine genotype has a shorter MRT substantiates the conclusion of Pond et al. (1987), which indicated that the volume of the colon of obese pigs was less than that of the other genotypes. It appears that digesta movement through the gut is very similar among the genotypes, as shown by the equal \(\lambda\) values, but because of the larger size of the gastrointestinal tract of lean and contemporary swine (Pond et al., 1980; Pond et al., 1987) the \(T\) is increased relative to obese swine fed at the same level of intake.

Although rate of passage was not determined for the pigs fed the low-fiber diet, a faster rate of passage for obese pigs also was anticipated. All three swine genotypes were fed equivalent rations; thus, with the observed smaller colon digesta content of obese pigs (Pond et al., 1987), either in vivo digestibility must be greater or rate of passage must be faster. Across both diets, obese swine had lower in vivo digestibility coefficients than lean or contemporary swine (Table 1). The in vitro data (Table 2) do not support the proposal of a higher digestibility of fiber by obese pigs. The faster rate of passage would explain the lower in vivo digestibility and smaller amount of digesta found in the obese pigs.

The reason for the greater number of bacteria that were cultured from obese pigs fed the high-fiber diet (10.2 \(\times 10^{10}\)) than from lean or contemporary pigs (6.6 \(\times 10^{10}\) and 6.7 \(\times 10^{10}\), respectively) is unknown (Table 3). This also may be associated with a faster rate of passage. Within each genotype no differences were found in the total bacterial count between the high-fiber or low-fiber diets. This agrees with other studies on total counts when high-fiber or low-fiber diets were fed (Varel et al., 1984a,b). The faster rate of passage of the intestinal tract of obese pigs may account for the slightly lower number of cellulolytic bacteria found there. Fermentation of fiber is strongly correlated with residence time (Van Soest, 1982); thus, a lower number of cellulolytic bacteria might be expected.

Age of the pigs, young adulthood, did not affect in vitro digestibility (Table 4). Bacterial populations appeared to adapt to the high-fiber diet within 14 d, and no changes in digestibility of fiber were seen after this initial 14-d period. Previously, we observed a 6.7-fold larger population of cellulolytic bacteria in the lower intestinal tract of the adult pig fed a high-fiber
diet than in the growing pig (Varel and Pond, 1985).

**Literature Cited**


