Effects of Dietary Fiber and Protein Concentration on Growth, Feed Efficiency, Visceral Organ Weights and Large Intestine Microbial Populations of Swine

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ABSTRACT **Finishing barrows (average initial weight 55.5 ± 2.4 kg) were used to determine the effects of high dietary fiber or protein on performance, visceral organ weights and large intestine microbial populations and to monitor the duration of regression of swine visceral organ mass and microbial populations to control values following transfer from the high fiber or high protein diet to the control diet. Four pigs from each diet were killed on d 17, 34, 48 and 66. From d 34 until slaughter 14 and 32 d later, all remaining pigs were fed the control diet ad libitum. High fiber resulted in significantly higher relative weight of the total gastrointestinal tract after 34 d and higher relative stomach weight up to d 48. Compared with the control diet, the high protein diet resulted in increased relative liver and kidney weights up to d 48. The number of proteolytic and cellulolytic bacteria increased in the colon contents of pigs fed a high protein or high fiber diet, respectively, but declined to below control values within 14 d of transferring pigs from the high protein or high fiber diet to the control diet. The results indicate that diet composition plays a more specific role in visceral organ hypertrophy than can be explained by the normal relative changes in organ size as body weight increases. Thus, high dietary fiber and protein may indirectly increase the animal's maintenance requirement by causing a repartitioning of nutrients from the edible carcass to the visceral organs.** *J. Nutr.* **119: 879–886, 1989.**

INDEXING KEY WORDS:

• *high dietary protein* • *dietary fiber* • *swine* • *visceral organ weights* • *large intestine microflora* • *Campylobacter sp.* • *cellulolytic bacteria* • *proteolytic bacteria*

Although visceral organ mass comprises only 10% or less of total body mass, the visceral organs account for a disproportionate share of whole body heat production (1–3). For example, heat production from metabolically active tissues accounted for more than 50% of the total heat expenditure of the ruminant (4), and heat production of the liver and gut represented about 20% of the fasting heat production of rats at rest (3). There is some evidence indicating that high fiber (5–7) and high protein (8) diets are associated with gastrointestinal tract hypertrophy, and that cellulolytic bacteria (9) and *Campylobacter* (10) are increased in the large intestine of pigs fed high fiber and high protein diets, respectively. Johnson (11) identified two general types of stimulation which result in growth of the gastrointestinal tract mucosa: *a*) nongastrointestinal hormones such as thyroxin and growth hormone, and *b*) factors acting in response to ingestion and digestion of food, including increased desquamation, gastrointestinal motility, endocrine and paracrine secretions and neural stimuli. The role of diet composition in visceral organ hypertrophy is unclear.

The objectives of this study were twofold: *a*) to determine the relative effects of diets high in fiber or protein on body weight gain, feed utilization, visceral organ weights and large intestine microbial (total anaerobes, *Campylobacter*, cellulolytic and proteolytic) population in swine; and *b*) to monitor the duration of regression of swine visceral organ mass and microbial populations to control values following transfer from diets high in fiber or protein to a standard diet.

MATERIALS AND METHODS

Animals and diets. Forty-eight crossbred (Chester White × Landrace × Large White × Yorkshire) fin-

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0022-3166/89 $3.00 Received 14 November 1988. Accepted 6 March 1989.

ishing barrows (average initial weight 55.5 ± 2.37 kg) produced at the Roman L. Hruska U.S. Meat Animal Research Center were divided into three groups of 16 and assigned randomly to the three diets shown in **Table 1**. The control diet was a 14.6% crude protein corn-soybean meal diet fortified with minerals and vitamins. The high fiber diet (16.4% crude protein) contained 40% alfalfa meal which substituted for part of the corn and soybean meal. In the high protein diet, soybean meal replaced 56% of the corn in the control diet to provide a 34% protein diet. Pigs were kept in pairs (eight pens of two pigs/diet) in 1.8 × 1.8 m concrete slotted floor pens in a temperature- and light-controlled building (20 ± 2°C, 12-h light/dark cycle) and fed their respective diets ad libitum.

Carcass analyses. Feed consumption of each pen of pigs was recorded fortnightly and at slaughter and body weight on d 1, 17, 34, 48 and 66. Four pigs fed each diet were killed at about 0900 h on d 17 and 34 without fasting. Carcass weight, length, cross-sectional area of the longissimus muscle at the 10–11th rib interface, weight of untrimmed and trimmed lean cuts (Boston butt, picnic, loin and ham) on the left side of the carcass, and weights of heart, liver, kidneys, spleen, leaf fat, empty stomach, small intestine and cecum-colon were recorded. Within 20 min after exsanguination, sections of stomach, jejunum, ileum and colon from four pigs in each group were fixed in 10% buffered formalin and preserved until sectioned (6 μ), stained with hematoxylin and eosin and examined histopathologically.

TABLE 1

Diet composition

Ingredient	Control	High fiber	High protein
		kg/100 kg	
Corn (No. 2 yellow)	82.1	50.6	26.1
Alfalfa meal		40.0	
Soybean meal (44% crude protein)	14.0	6.0	70.0
Dicalcium phosphate	2.4	2.4	2.4
Limestone	0.5		0.5
NaCl (iodized)	0.4	0.4	0.4
Trace mineral premix[1]	0.2	0.2	0.2
Vitamin premix[2]	0.2	0.2	0.2
Choline chloride	0.2	0.2	0.2
Analyzed composition, %			
Dry matter	89.7	89.6	90.3
Crude protein	14.6	16.4	34.1
Acid detergent fiber	4.5	16.2	7.6
Cell walls	10.0	24.9	10.1
Cellulose	3.7	12.5	6.7
Lignin	1.3	4.3	1.5
Ash	5.7	6.8	7.1
Metabolizable energy *kcal/kg* calculated	3,047	2,606	3,147

[1]Supplied the following (mg/kg of complete diet): $CuSO_4 \cdot 5H_2O$, 10; $FeSO_4 \cdot 7H_2O$, 160; MnO, 20; ZnO, 100; $CaCO_3$ as a carrier.

[2]Supplied the following (mg/kg of complete diet except as noted): retinyl palmitate, 5,280 IU; cholecalciferol, 704 IU; *dl*-α-tocopheryl acetate, 32.5; menadione sodium bisulfite, 3.52; vitamin B-12, 26.4 μg; riboflavin, 5.28; niacin, 28.16; *d*-pantothenic acid, 21.12; biotin, 88 μg; thiamin, 2.2. The vitamin supplement was custom-mixed by International Nutrition, Omaha, NE.

Microbial analyses. A sample of colon contents was removed from each pig at slaughter for microbial counts of total anaerobes, cellulolytic bacteria, proteolytic bacteria, *Campylobacter* and *Salmonellae*. Total anaerobes and cellulolytic bacteria were enumerated as previously described (12). Proteolytic bacteria were enumerated by comparing colony number and size in media with and without 1.5% Trypticase (BBL Microbiology Systems, Cockeysville, MD). The basal medium consisted of (per 100 ml): clarified pre-incubated rumen fluid, 5.0 ml; mineral S2 (12), 5.0 ml; vitamin solution (13), 5.0 ml; volatile fatty acid solution (13), 0.22 ml; and purified agar (BBL), 1.75 g. Sodium carbonate and cysteine-hydrochloride were added after media sterilization. Only pinhead size colonies developed in the medium without Trypticase, whereas the medium with Trypticase contained colonies much larger and thus considered to be proteolytic. For *Enterobacteriaceae* and *Campylobacter* sp., composite samples were prepared by pooling samples of colon contents from two animals. Two composite samples per treatment were analyzed on each slaughter date. *Enterobacteriaceae* were enumerated using Videt Red Bile Glucose agar (Oxoid, Columbia, MO) and the pour plate technique (14). The plates were incubated at 37°C for 24 h. *Campylobacter* sp. were enumerated by the spread plate method (14) using the *Campylobacter* agar kit with Blaser supplements (Difco, Detroit, MI) and 10% bovine blood. The plates were incubated at 43°C for 48 h under a modified atmosphere (Campy Pak Plus; BBL, Cockeysville, MD) in anaerobe jars. Representative colonies showing typical morphology on the agar were confirmed by cell morphology, motility and catalase reactions. *Salmonellae* were enumerated using a modified most-probable-number method (15).

From d 34 until slaughter 14 and 32 d later (48 and 66 d after beginning of experiment), all remaining pigs were fed the control diet ad libitum. Four pigs from each group were slaughtered on d 48 and 66 and the same measurements were taken as on d 17 and 34. For pigs slaughtered on d 66, backfat depth (mean of three measurements taken on the split carcass at the first and last ribs and last lumbar vertebra) was also recorded.

Data analysis. Data were subjected to a 3 × 4 factorial least-squares analysis of variance (16) with diet and time of slaughter as main effects. Differences among diets within slaughter dates were tested by least significant difference. Pen was the experimental unit for

weight gain and feed data and individual animal for carcass, visceral organ and microbiological data.

RESULTS

Data on growth and feed efficiency of pigs are shown in **Table 2**, and those on carcass traits and relative weights of carcass and lean cuts in **Tables 3** and **4**, respectively.

There were significant diet × time interactions with respect to daily gain (Table 2) and relative carcass weight (carcass weight expressed as a percent of body weight, Table 3). Daily gain was significantly depressed by the high fiber diet compared to the control and high protein diets on d 17 and 34, and compared to the control diet only up to d 48. By d 66, there were no significant differences among treatments in daily gain. Although the high protein diet produced weight gains that were only 84, 80 and 84.5% of those produced by the control diet on d 17, 34 and 48, respectively, these differences were not significant. Daily feed consumed and gain-to-feed ratios (Table 2) were significantly depressed by the high fiber diet relative to the control and high protein diets by d 17 only. Daily feed consumed and gain-to-feed ratios did not differ significantly between pigs fed the control or high protein diet.

As expected, slaughter date had significant effects on area of longissimus muscle, weight and length of carcass, relative carcass weight and absolute and relative weights of the trimmed lean cuts (Table 3). Feeding the high fiber diet resulted in significantly lower area of the longissimus muscle, lower absolute and relative carcass weight compared with the control diet up to d 34, and lower absolute weights of the carcass and trimmed lean cuts up to d 48. By d 66, there were no significant differences between pigs fed the control and high fiber diets, except in absolute carcass weight in which values for pigs fed high fiber were still lower than control values. Relative to the control diet, the high protein diet had no effect on carcass traits. Backfat depth on d 66 did not differ significantly among diet groups.

Slaughter date had significant effects on absolute and relative weights of all visceral organs measured, as expected, except for absolute weight of kidneys and relative weight of spleen (Table 4). Diet had significant effects on absolute weights of all visceral organs except total gastrointestinal tract and small intestine (**Table 5**) and on relative weights of all organs except heart, spleen, large intestine and small intestine (Table 4, 5). There were significant diet × time interactions in absolute weights of liver and kidneys and relative weights of heart, liver, kidneys and stomach. High dietary fiber resulted in lower weights of liver and large intestine and lower relative weight of liver on d 17; lower absolute weights of heart and spleen and high relative weight of stomach on d 34; and lower absolute weights of heart and leaf fat and lower relative weight of leaf

TABLE 2

***Effect of dietary fiber and protein on growth and feed efficiency of pigs at different slaughter times*[1]**

Slaughter time	Diet		Slaughter weight	Daily gain	Daily feed	Gain/feed ratio
d		*n*[2]	*kg*	*kg*	*kg*	
17	C	4	65.8[a]	0.62[a]	2.73[a]	0.23[a]
	HF	4	54.4[b]	−0.08[b]	0.67[b]	−0.12[b]
	HP	4	63.9[a]	0.52[a]	2.35[a]	0.22[a]
34	C	4	80.8[a]	0.74[a]	2.22	0.33
	HF	4	68.9[b]	0.39[b]	1.59	0.25
	HP	4	75.6[a]	0.60[a]	2.30	0.26
48	C	4	96.5[a]	0.84[a]	2.51	0.33
	HF	4	83.3[b]	0.57[b]	2.07	0.28
	HP	4	89.8[ab]	0.71[ab]	2.26	0.31
66	C	4	108.1	0.81	2.70	0.30
	HF	4	103.8	0.73	2.61	0.28
	HP	4	109.0	0.81	2.65	0.31
	SEM[3]		2.68	0.08	0.24	0.08
				P-values[4]		
	Time (T)		0.01	0.01	NS	NS
	Diet (D)		0.01	0.01	0.04	0.05
	T × D		0.01	0.01	NS	NS

[1]Values are least-squares means; C = control diet, HF = high fiber diet, HP = high protein diet. [ab]Means in the same column within the same slaughter time not sharing a common superscript letter are significantly different.

[2]Mean initial weight per group was 55.5 ± 2.4 kg (range 54.9 to 56.0 kg); $n = 2$ for statistical analysis (2 pigs per pen, 2 pens per diet per slaughter time).

[3]Standard error of the mean.

[4]NS = Not significant ($P > 0.10$).

TABLE 3

Effect of dietary fiber and protein on carcass traits and weights of lean cuts at different slaughter times[1]

Slaughter time	Diet	Longissimus muscle	Carcass length	Average backfat	Cold carcass		Trimmed lean cuts		Leaf fat	
d		*cm*[2]	*cm*	*cm*	*kg*	%[2]	*kg*[3]	%[4]	*kg*	%[2]
17	C	23.2[a]	70.0	—	38.4[a]	58.3	25.1[a]	65.5	0.63	0.96[a]
	HF	19.2[b]	68.7	—	31.4[b]	57.6	20.9[b]	66.6	0.41	0.74[b]
	HP	21.8[ab]	71.0	—	36.3[ab]	56.7	22.7[ab]	63.0	0.36	0.58[b]
34	C	28.3[a]	75.2	—	49.7[a]	61.5[a]	30.7[a]	61.8		
	HF	24.8[b]	71.3	—	39.0[b]	56.6[b]	25.5[b]	65.7		
	HP	25.5[ab]	74.6	—	45.3[a]	59.9[a]	29.1[a]	64.2		
48	C	29.8[ab]	77.8	—	60.8[a]	63.3[a]	35.0[a]	57.6	1.48[a]	1.51[a]
	HF	27.1[a]	77.2	—	54.9[b]	65.8[ab]	30.8[b]	56.3	0.94[b]	1.12[b]
	HP	32.3[b]	78.1	—	60.6[a]	67.5[b]	35.4[a]	58.5	0.98[b]	1.10[b]
66	C	35.8	79.6	1.49	76.2[a]	70.3	40.8	53.5	1.84	1.70
	HF	33.0	79.6	1.42	70.8[b]	68.2	38.6	54.6	1.62	1.55
	HP	35.5	79.4	1.44	74.6[ab]	68.4	39.9	53.5		
	SEM[5]	1.47	1.41	0.01	2.10	1.09	1.25	1.42	0.15	0.14
					P-values[6]					
	Time (T)	0.01	0.01	—	0.01	0.01	0.01	0.01	0.01	0.01
	Diet (D)	0.01	NS	NS	0.01	NS	0.01	NS	0.02	0.02
	T × D	NS	NS	—	NS	0.02	NS	NS	NS	NS

[1]Values are least-square means for four pigs per group. C = Control diet, HF = high fiber diet, HP = high protein diet. [abc]Least-squares means in each column within each slaughter time not sharing a common superscript letter are significantly different.
[2]Expressed as a percent of body weight.
[3]Combined weight of ham, loin, Boston butt, and picnic.
[4]Expressed as a percent of cold carcass weight.
[5]Standard error of the mean.
[6]NS = Not significant ($P > 0.10$).

fat, but higher relative weight of stomach, on d 48. By d 66, there were no significant differences between pigs fed the control or high fiber diet in absolute and relative weights of all organs except relative weight of the liver, which was now higher in pigs fed the high fiber diet. Histopathological examination of sections of stomach, jejunum, ileum and colon of four pigs in each diet group revealed no evidence of pathologic lesions associated with diet.

Compared to the control diet, the high protein diet resulted in significantly higher absolute and relative liver weight and relative kidney weight, but significantly lower relative stomach and leaf fat weights, on d 17; significantly higher absolute and relative liver and kidney weights on d 34; and significantly higher relative liver and kidney weights, but lower absolute and relative leaf fat weight, on d 48. By d 66, all significant differences between control and high protein diet groups had disappeared.

Feeding the high fiber diet resulted in lower absolute and relative liver and kidney weights, lower absolute large intestine weight and higher absolute and relative stomach weights than the high protein diet on d 17; lower absolute and relative heart, liver and kidney weights, lower absolute spleen weight, but higher absolute and relative stomach weight, on d 34; and lower absolute heart, kidney and spleen weight on d 48. By d 66, there were no significant differences between pigs fed the high fiber or high protein diet except for the relative weight of kidneys, which was higher in pigs fed the high fiber diet.

Diet, time and diet × time interactions were significant for total number of anaerobic, proteolytic, cellulolytic and *Campylobacter* bacteria cultured from colon contents, but not significant for *Enterobacteriaceae* (**Table 6**). The number of proteolytic bacteria was greater from pigs fed the high protein diet (d 17 and 34) than those fed the control or high fiber diet. By d 66, the number of proteolytic bacteria was similar for all pigs. The number of cellulolytic bacteria on d 34 was greater for those pigs fed the high fiber diet than those fed the control or high protein diet. Again by d 66, the number of cellulolytic bacteria was similar for all pigs. The number of total anaerobic bacteria cultured was greater from the pigs fed the high protein diet at d 17, and least from the pigs fed high fiber at d 34. Similar numbers of anaerobes were observed from all pigs on d 48. Unexpectedly, the number of anaerobes found in the colon contents of pigs originally fed the high protein diet was greater on d 66 than in those fed the other two diets.

On d 17, there were no significant differences due to diet in number of *Campylobacter* sp., but by d 34 their numbers were significantly lower in pigs fed the high fiber diet than in those fed the control or high protein

TABLE 4

Effect of dietary fiber and protein on organ weights of finishing pigs slaughtered at different times[1]

Slaughter time	Diet	Heart	Liver	Kidneys	Spleen	Heart	Liver	Kidneys	Spleen
d		*g*	*kg*	*g*	*g*		*% of body weight*		
17	C	210.9	1.11[a]	229.0[ab]	80.3	0.32	1.68[a]	0.35[a]	0.12
	HF	183.7	0.82[b]	196.7[b]	69.3	0.34	1.52[b]	0.36[a]	0.13
	HP	202.2	1.28[c]	280.2[a]	85.6	0.32	2.00[c]	0.44[b]	0.13
34	C	239.9[a]	1.24[a]	254.1[a]	100.4[a]	0.30	1.53[a]	0.31[a]	0.13
	HF	193.0[b]	1.14[a]	220.1[a]	80.3[b]	0.28	1.65[a]	0.32[a]	0.12
	HP	241.9[a]	1.49[b]	325.7[b]	100.0[a]	0.32	1.97[b]	0.43[b]	0.13
48	C	262.6[a]	1.46	250.1[ab]	110.4[a]	0.27	1.51[a]	0.26[a]	0.12
	HF	229.1[b]	1.33	237.0[b]	89.4[b]	0.28	1.60[ab]	0.28[ab]	0.11
	HP	267.3[a]	1.49	291.5[a]	108.9[a]	0.30	1.66[b]	0.32[b]	0.12
66	C	294.7	1.58	255.6	128.0	0.27	1.47[a]	0.24[ab]	0.12
	HF	297.8	1.71	292.7	127.8	0.28	1.65[b]	0.28[a]	0.12
	HP	298.6	1.66	248.2	135.9	0.27	1.52[ab]	0.23[b]	0.12
	SEM	12.5	0.07	22.1	7.42	0.01	0.06	0.02	0.01
					P-values[2]				
	Time (T)	0.01	0.01	NS	0.01	0.01	0.01	0.01	NS
	Diet (D)	0.01	0.01	0.01	0.01	NS	0.01	0.01	NS
	T × D	NS	0.03	0.06	NS	0.08	0.01	0.01	NS

[1]Values are least-square means for four pigs per group. C = Control diet, HF = high fiber diet, HP = high protein diet. [abc]Means in the same column within the same slaughter time not sharing a common superscript letter are significantly different.

[2]NS = Not significant ($P > 0.10$).

diet. By d 48, these differences had disappeared, but by d 66, pigs originally fed the control diet had significantly lower *Campylobacter* numbers than those originally fed the high fat or high protein diet. With the exception of a 34-d peak, there were no differences at different slaughter times in the numbers of *Campylobacter* sp. found in the pigs fed the control diet. The high protein diet produced an almost linear increase in the numbers of *Campylobacter* during the first 34 d, after which the numbers decreased as the pigs returned to the control diet.

All of the samples from pigs fed the control and high protein diets tested negative for *Salmonellae*. Low numbers of *Salmonellae* [log 1.74 colony forming units (cfu)/g] were found on d 17 only in samples from pigs fed the high fiber diet.

DISCUSSION

The observed growth response of the liver, kidneys and specific gastrointestinal tract segments to changes in diet composition in ad libitum–fed growing animals within 2 to 3 wk after introduction of the dietary changes supports the concept of nutritionally induced repartitioning of nutrients among organ systems. The liver and kidney hypertrophy associated with intake of the high protein diet was probably related to the higher amounts of nitrogenous compounds processed by these organs; the hypertrophic effect was shown to be reversed at 34 d, but not within 2 wk after return to the control diet. Relative liver weight is known to increase steadily in growing rats adapting to a high protein (90% casein) diet for 7 d (17). The hypertrophic effect of high fiber diets on the gastrointestinal tract in growing pigs has been reported repeatedly (5–7, 10), but the duration of the high fiber feeding period has been much longer than in the present work. The increase in relative stomach weight observed after only 17 d on the high fiber diet in the present work was in spite of decreased feed intake of the pigs fed the high fiber diet relative to control pigs, showing that the increase was not just a result of physical expansion. There was no significant increase in the weight of either small or large intestine after 34 d in this study, suggesting that the hypertrophy reported previously (5–7, 10) required more than 34 d to be manifested. The failure to observe hypertrophy or histopathological changes in gastrointestinal tract segments in response to high dietary protein is in contrast to previous work (10) of longer duration (84 d); the shorter duration of feeding high protein in this experiment (34 d) may have precluded showing the hypertrophic effect of high protein on gastrointestinal tract tissues. The lack of an effect of diet (except for that of the high fiber diet on stomach) on weights of gastrointestinal tract segments after 17 or 34 d was supported by the observed absence of pathologic changes in tissue sections taken from stomach, small intestine and large intestine at slaughter.

Daily feed consumption and gain-to-feed ratios were significantly depressed by the high fiber diet only during the first 17 d, indicating adaptation to the high fiber

TABLE 5

Effect of dietary fiber and protein on stomach, large intestine and small intestine of pigs slaughtered at different times[1]

Slaughter time	Diet	Total GI tract	Stomach	Large intestine	Small intestine	Total GI tract	Stomach	Large intestine	Small intestine
d		*kg*	*g*	*kg*	*kg*		*% of body weight*		
17	C	2.66	402.7[ab]	1.25[a]	1.01	4.05	0.61[a]	1.89	1.55
	HF	2.22	423.6[a]	0.93[b]	0.86	4.08	0.78[b]	1.72	1.58
	HP	2.61	359.1[b]	1.19[a]	1.06	4.08	0.56[c]	1.84	1.68
34	C	2.85	484.5[ab]	1.34	1.02	3.54[a]	0.60[a]	1.67	1.26
	HF	2.72	530.3[a]	1.19	1.00	3.94[b]	0.77[b]	1.72	1.45
	HP	2.84	442.8[b]	1.33	1.07	3.75[ab]	0.58[a]	1.76	1.41
48	C	3.24	503.6	1.42	1.31	3.37	0.52[a]	1.48	1.37
	HF	3.05	482.2	1.37	1.20	3.71	0.58[b]	1.66	1.46
	HP	3.18	484.8	1.35	1.35	3.55	0.54[ab]	1.50	1.51
66	C	2.76	488.0	1.31	0.96	2.55	0.45	1.21	0.89
	HF	3.01	513.2	1.37	1.13	2.90	0.49	1.32	1.09
	HP	2.94	501.6	1.50	0.94	2.69	0.46	1.37	0.86
	SEM	0.13	26.0	0.09	0.07	0.17	0.02	0.10	0.11
						P-values[2]			
	Time (T)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	Diet (D)	NS	0.10	0.09	NS	0.08	0.01	NS	NS
	T × D	NS	NS	NS	NS	NS	0.01	NS	NS

[1]Values are least-square means for four pigs per group. C = control diet, HF = high fiber diet, HP = high protein diet. [ab]Means in the same column within the same slaughter time not sharing a common superscript letter are significantly different.

[2]NS = not significant ($P > 0.10$).

diet with continued feeding. The depression of daily weight gain by the high fiber diet for up to 14 d after the pigs had been switched to the control diet was associated with reduced indices of lean tissue accretion immediately following the period of high fiber intake. Relative carcass weight and weights of lean cuts, however, were depressed only during the period the pigs were consuming the high fiber diet. Relative weights of lean cuts were not significantly affected by feeding a high fiber diet, indicating that the differences in absolute weights of lean cuts were related to body weight. The elevated relative carcass weight and reduced leaf fat weights up to d 48 in pigs fed the high protein diet reflect the leaner carcasses in this group than in the controls.

The elevated relative stomach weight (up to 14 d after switching pigs to the control diet) in response to high dietary fiber, and increased relative liver and kidney weights in response to high dietary protein, have important implications for meat animals because of the established significant and positive correlations ($r \geq 0.98$) between fasting heat production of pigs and the weights of the stomach, small intestine, large intestine, pancreas, liver and kidneys (18, 19). Energy expenditure by the metabolically active tissues such as liver, gut and kidneys is much higher than energy expenditure associated with the carcass (20), accounting for more than 50% of the energy expenditure by the whole animal (4). There is evidence to show that increases in apparent maintenance requirement during pregnancy and lactation of rats are due in part to increases in weight and metabolic activity of the visceral organs (21). It thus appears that high dietary fiber and protein indirectly increase the animal's maintenance requirement by causing a repartitioning of nutrients from the growth of the edible carcass to the visceral organs and consequently increasing visceral organ mass.

As expected, the number of protein-hydrolyzing bacteria increased in the colon contents of pigs fed the high protein diet when compared to control animals. This suggests that more protein substrate is entering the colon of these pigs than control pigs, thus causing these bacteria to flourish. A similar response was seen with the number of cellulolytic bacteria from the pigs fed the high fiber diet; however, the greater number of cellulolytic bacteria was not seen until d 34, while the greater number of proteolytic bacteria from the pigs fed the high protein diet was apparent at d 17. Once these pigs were switched from the high protein and high fiber diets to the control diet (after d 34), similar numbers of proteolytic and cellulolytic bacteria were observed from these animals as from pigs fed the control diet. These results suggest that it may take a longer time for fiber-degrading bacteria to establish and stabilize in the pig intestinal tract, as compared to proteolytic bacteria. This is likely because bacterial growth rates are normally faster on soluble vs. insoluble substrates.

The reasons for the higher number of anaerobes found on d 66 in the colon of pigs originally fed the high protein diet, the higher number of *Campylobacter* in

TABLE 6

Effect of dietary fiber and protein on microbial populations of finishing pigs at different slaughter times[1]

Slaughter time	Diet	Anaerobes	Proteolytic bacteria	Cellulolytic bacteria	*Campylobacter* sp.	*Entero-bacteriaceae*
d				*log 1.74 cfu/g*[2]		
17	C	10.87[a]	10.17[a]	8.79[a]	4.89	7.85
	HF	10.85[a]	10.13[a]	8.81[a]	6.14	6.40
	HP	11.18[b]	10.35[b]	8.41[b]	6.33	6.81
34	C	11.09[a]	10.02[a]	8.23[a]	7.69[a]	6.56
	HF	10.66[b]	9.96[a]	8.69[b]	5.86[b]	6.34
	HP	11.23[a]	10.38[b]	8.20[a]	7.63[a]	7.40
48	C	10.70	9.86[a]	8.70[a]	5.22	6.43
	HF	10.61	9.72[b]	8.11[b]	5.13	6.32
	HP	10.70	9.91[a]	8.28[b]	6.24	7.23
66	C	10.90[a]	9.69	8.72	5.93[a]	6.37
	HF	10.90[a]	9.63	8.59	7.16[b]	6.45
	HP	11.11[b]	9.68	8.45	7.34[b]	6.35
	SEM	0.08	0.05	0.10	0.36	0.43
				P-values[3]		
	Time (T)	0.01	0.01	0.01	0.01	NS
	Diet (D)	0.01	0.02	0.01	0.01	NS
	T × D	0.01	0.04	0.01	0.01	NS

[1]Values are least-square means for four pigs per group. C = control diet, HF = high fiber diet, HP = high protein diet. [ab]Means in the same column within the same slaughter time not sharing a common superscript letter are significantly different.

[2]cfu = Colony forming units.

[3]NS = not significant ($P > 0.10$).

pigs fed a high fiber or high protein diet on d 66, and the peak of *Campylobacter* in control animals on d 34, are unknown. The low numbers of *Salmonellae* found on d 17 only in pigs fed the high fiber diet and the inability to detect *Salmonellae* in any group on all other days indicate that *Salmonellae* were merely transient inhabitants of the gastrointestinal tract.

While the numbers of total anaerobes, proteolytic bacteria and *Campylobacter* sp. were highest in pigs fed the high protein diet on d 17 and 34, the number of cellulolytic bacteria and relative weight of the stomach were greatest in pigs fed the high fiber diet. Thus, relative stomach weight was more directly related to the numbers of cellulolytic bacteria and appeared to be inversely related to numbers of anaerobes, proteolytic bacteria and *Campylobacter* sp. An increase in relative weight of the stomach in rats fed a high fiber diet has been reported (10). Although feeding a high fiber diet to swine for up to 84 d increased relative weights of small and large intestine (10), no such effect was produced in the present study, probably because of the relatively shorter duration (34 vs. 84 d) of feeding the high fiber diet.

We conclude that diet composition plays a more specific role in visceral organ hypertrophy than can be explained by normal relative increases in organ size as body weight increases. Most affected organs did not regress to control values within 14 d of switching the pigs from a diet containing high fiber or protein to the control diet, but by 32 d after switching, all visceral organs, except the liver in pigs fed high fiber, did regress to control values.

ACKNOWLEDGMENTS

We express our appreciation to Ted Acton, Jenell Dague and associates for animal care and feeding; Pat Reiman and associates for feed mixing; Jeff Waechter and associates for feed analyses; Sandy Cummins, Candy York, Christi Beach, Terry Alberts and Tammy Struehm for laboratory technical assistance; Dave Kohmetscher and associates for animal slaughter and carcass measurements; and Sherry Hansen for technical assistance with manuscript preparation.

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