Comparison of Digestive Function Among Rabbits, Guinea-Pigs, Rats and Hamsters. I. Performance, Digestibility and Rate of Digesta Passage

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ABSTRACT : This trial was to compare the digestive function of laboratory animals, which included omnivores (rats) and herbivores (rabbits, guinea pigs and hamsters). Ten weanling rats, rabbits, guinea pigs and hamster were randomly allocated in individual metabolic cages for a performance and a digestibility trial. Results showed that guinea pigs were significantly best in digestion of dietary crude protein and fiber. Rabbits, however, had the poorest nutrient digestion among the herbivores. Crude fiber digested significantly less by rats than by the herbivores ($p<0.05$). The digesta retention in the GI tract was longest in rabbits followed by guinea pigs, rats and hamsters. The relative length of the large intestine was significantly shorter in rats as compared to guinea pigs or hamsters. Both the weight and length ratio of the caecum or colon-rectum to the large intestine reflected the major site for fermentation that was the caecum in rabbits and the colon-rectum in guinea pigs. 10% of crude fiber diet did not result in damaged mucosa in any of the experimental animals in this trial. *(Asian-Aus. J. Anim. Sci. 2000. Vol. 13, No. 11 : 1499-1507)*

Key Words : Herbivores, Laboratory Animals, Performance, Digestibility, Rate of Digesta Passage, Crude Fiber

INTRODUCTION

The animals that are most extensively use in the laboratory are rabbits, guinea pigs, rats and hamsters. These animals are all hindgut fermenters and herbivores, except rats which are omnivores. Growing rabbits (NRC, 1977) and guinea pigs (NRC, 1995) require 10~12% and 15% crude fiber, respectively, in their diet. Although the specific amount of crude fiber required by rats and hamsters has not yet been determined, the crude fiber in their diets has generally been emphasized due to its significance in digestive function. Research data have suggested that a 10% dietary fiber or cell wall is required in the diet for rats (Nyman and Asp, 1985; Pond et al., 1989). The hindgut which includes the caecum, colon and rectum is the major site of fermentation in these herbivore non-ruminants, where volatile fatty acids (VFA), end products of fermentation, are absorbed by the host animal as an energy source (Parker and McMillan, 1976; Zhao et al., 1995). Cecotomy of these animals significantly depressed rat and hamster ability to digest dietary dry matter and crude fiber (Sakaguchi et al., 1981; Williams and Senior, 1982), but showed no significant impact in rabbits (Gioffre et al., 1980).

Rabbits are not good digesters of fiber. They digest crude fiber less well as compared to guinea pigs, but can digest cellulose and hemicellulose as well as rats (Fonnesbeck et al., 1974). Rabbits, however, cannot survive on a low fiber diet (6% of crude fiber). This is also true for rats and hamsters on a crude fiber free diet. Feeding rats and hamsters on this kind of diet causes high mortality or depressed growth (Cheeke and Patton, 1980). On the other hand, dietary crude fiber is beneficial to guinea pigs in depressing the growth of pathogenic bacteria, *Bacteroides ovatus*, in the intestine, hence improving the growth of guinea pigs (Johanning et al., 1984).

Increased levels of crude fiber in the diet generally decrease feed conversion efficiency in rabbits and rats. This may be attributed to the changes in the GI tract that enhance the digestive function in these animals. In the rats an increase in the level of dietary fiber significantly increases the intestinal weight and length of various sections of the GI, but decreases nitrogen retention which results in decreased growth (Zhao et al., 1995). For non-ruminant herbivores, dietary fiber is therefore, significant as a source of bulk in the digestive physiology, not as a source of nutrients.

The biological classifications of these laboratory animals are closely related. Rabbits belong to the order of Lagomorpha, Rats and hamsters belong to order of Rodentia and guinea pigs are hystricomorph. Some specific digestive functions in the various sections of the GI tract should be similar among these animals. Research information is limited on the comparative effects of crude fiber on their digestion. This trial is therefore aimed at study of the differences in digestive function in these laboratory animals and their utilization of crude fiber.

MATERIALS AND METHODS

Animal and diets

Ten four-week old weanlings of each animal species with equal numbers of each sex and a mean live-weight of 1,021 g for the California rabbit, 175 g for the Hartley guinea pig, 165 g for the Wistar rat

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Received January 26, 2000; Accepted June 27, 2000

and 71 g for the Syrian hamster, were selected for this feeding trial. These animals were from the National Laboratory Animal Breeding and Research Center at Taiwan. The experimental diet is presented in table 1. This diet was formulated to contain 18% crude protein and 10% crude fiber according the nutrients requirement for rabbits (NRC, 1977), and laboratory animals (Sakaguchi et al., 1987; NRC, 1995). The diet was presented in pellet form with size of 0.6 by 1.5 cm.

Feeding trial and digestibility trial

All experimental animals were randomly allocated in individual metabolic cages. After one week of adaptation, the animals began the four-week feeding trial in growing period. These animals were individually fed *ad libitum* once daily at 7:00 AM. Water was provided with free access. Additional ascorbic acid was provided through drinking water (200 mg/L) for guinea-pigs. Light period was 12L:12D and ambient temperature set at 23+1℃ with 40-70% humidity.

During the feeding period, feed intake and live-weight were recorded weekly. A digestion trial was conducted at the end of the feeding trial that included three days of adaptation followed by five days of total fecal collection.

Determination of digesta retention time

Four animals with equal numbers of each sex from each species of animal were selected for the digesta retention study. The animals were fasted for 8 hours before being fed for three hours on a marker diet (1% Cr_2O_3). After 3 hours of feeding, animals were returned to feeding on the basal diet. Feces were collected every single hour within the first 48 hours after animals were fed the marker diet. From the 48th to the 72nd hour after marker diet feeding, feces were collected every four hours for analysis of Cr_2O_3.

The turnover time of each marker was estimated from the decline in the fecal marker concentration according to the following equation (Brandt and Thacker, 1958)

$$Y = Y_o \times e^{-kt}$$

Where Y is the concentration of Cr_2O_3 in feces at time t; Y_o is the constant depending on the level of Cr_2O_3 fed; k is the rate constant; t is the time interval after feeding of the marker (h).

Turnover time was calculated as the reciprocal of k. Total mean retention time (MRT) in the gastro-intestinal tract was calculated as the sum of k^{-1} and the transit time (TT). Transit time equaled the first appearance of the marker after a dose.

The GI tract histology and morphology by SEM

At the end of the fecal collection, all animals were sacrificed after 12 hours fasting. The intestinal tracts were then removed to measure the weight and length of each intestine segment. These gut segments included stomach, duodenum (from pylorus to end of duodenal loop), jejunum, ileum, cecum, colon and rectum.

A two-centimeter section of the caecal and the colonic-rectal samples were taken and rinsed with 0.4 M KCl. A 0.5-cm section of sample was taken with a sharp knife for electron microscope (SEM) scanning according to Paulini et al. (1987) and Moore et al. (1988). All samples were fixed initially in 10% buffered formalin pH 7.0. The specimens were washed (0.1 M phosphate buffer pH 7.3, 3 times for 10 min), and placed in 1% osmium tetroxide for 1 hour. These samples were washed again (phosphate buffer 4 times for 15 min) and then gradually dehydrated by increasing the alcohol concentrations: 50, 70, 80, 90 and 95% for 10 to 15 min each time until finally the concentration was increased to 100% - 3 times. Specimens were then subjected to critical point drying and mounting on aluminium stubs, coated with gold for half an hour and placed in the SEM (Bausch & Lomb Ltd., Nonolab 2100) for scanning.

Analytical methods

The fecal samples from the digestion trial and the passage rate trial were oven dried at 60℃ for three days, followed by two days at room temperature, and

Table 1. Composition of experiment diet (%)

Ingredients	
Ground corn	38.95
Wheat bran	6.0
Soybean meal	21.0
Alfalfa meal	29.0
Soybean oil	2.5
Dicalcium phosphate	2.0
Salt	0.5
Premix*	0.05
Total	100.0
Analyzed value	
Dry matter	90.46
Crude protein	17.56
Crude fiber	9.83
Neutral detergent fiber	20.96
Acid detergent fiber	11.26
Ash	4.74

* Premix (Per kg of diet): Cu($CuSO_4 \cdot 5H_2O$), 8 mg; Fe($FeSO_4 \cdot 7H_2O$), 80 mg; Zn($ZnSO_4$), 120 mg; Mn($MnSO_4 \cdot 5H_2O$), 140 mg; Choline (chloride), 1 g; Vitamin B_6, 40 mg; Vitamin B_2, 80 mg; Niacin, 200 mg; Vitamin E, 50 mg; Ascorbic acid, 200 mg.

then ground. The dry matter, crude protein, crude fiber in the feed and feces were analyzed according to the methods of the AOAC (1980). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were measured according to Van Soest et al. (1991) using an amylolytic pretreatment with a thermostable amylase. The concentrations of Cr_2O_3 in the feed and feces were measured according to the method described by Williams et al. (1962).

Statistical analysis

Variance analyses of the results were calculated with the General Linear Model Procedure (GLM) of the Statistical Analysis System (1985). Duncans New Multiple Range test was used to compare the effect on the animal species according to the procedure of Steel and Torrie (1960).

RESULTS

Table 2 presents the live-weight, live-weight gain and feed intake of the rabbits, guinea pigs, rats and hamsters after four weeks of feeding. Rabbits attained the heaviest daily live-weight gain while guinea pigs grew the most rapidly with the best rate of live-weight gain (live-weight gain/live-weight at the beginning of the trial). Rabbits and rats were next, while hamsters grew the slowest among the treated animal species. Feed intake was significantly greater in hamsters and rats as compared to guinea pigs and rabbits when expressed in relation to live-weight. Rats however ate significantly more feed ($p<0.05$) and hamsters ate significantly less than the other species ($p<0.05$) when feed intake expressed in metabolic body weight ($W^{0.75}$). Rabbits and guinea pigs utilized feed more efficiently ($p<0.05$) than rats and hamsters ($p<0.05$).

The apparent digestibility of nutrients in the four different animals is presented in table 3. Guinea pigs showed thr significantly highest ability to digest dry matter, crude protein, crude fiber, NDF and ADF over the other animals ($p<0.05$), followed by hamsters. Rabbits and rats exhibited a poorer ability to digest crude protein than guinea pigs and hamsters ($p<0.05$). On the other hand, rats (omnivores) exhibited significantly poorer digestion of crude fiber, NDF and ADF than the other animals ($p<0.05$).

The turnover time (k^{-1} or dilution rate), the transit time (time of the first appearance of the marker in feces, TT) and the mean retention time (MRT) of digesta in rabbits, guinea pigs, rats and hamsters are shown in table 4. From the k^{-1} value and MRT, the significantly longest retention of the marker was in the GI tract of rabbits, followed by guinea pigs, hamsters, and rats, which was the shortest ($p<0.05$).

Figure 1 shows the principal parts of the dissected gastrointestinal tracts of the four laboratory animals. Apparent differences in relative sizes of the various

Table 2. Body weight, weight gain and feed intake in rabbits, guinea pigs, rats and hamsters

Items	Rabbits	Guinea pigs	Rats	Hamsters
Live-weight, g				
At the beginning	1,021 ± 89[1]	175 ± 15	165 ± 31	71 ± 7
At the end	1,913 ±266	376 ± 43	310 ± 79	116 ± 9
Daily weight gain, g	31.8 ± 6.51[a]	7.2 ± 1.09[b]	5.2 ± 1.62[bc]	1.6 ± 1.28[c]
Daily gain rate[2], %	3.1 ± 0.64[b]	4.1 ± 0.67[a]	3.1 ± 0.56[b]	2.2 ± 0.44[c]
Feed efficiency, feed/gain	2.9 ± 0.50[c]	3.4 ± 0.42[c]	5.1 ± 1.69[b]	6.6 ± 1.32[a]
Daily feed intake g/kg live weight	66.5 ± 5.96[c]	98.0 ± 3.18[b]	112.7 ± 6.04[a]	114.7 ± 7.16[a]
Daily feed intake g/kg live-weight$^{0.75}$	71.1 ± 6.80[b]	68.7 ± 2.74[b]	76.3 ± 3.45[a]	62.5 ± 3.43[c]

[1] Mean ± SD (n=10).

[2] Daily weight gain rate (%)=Daily weight gain (g)/Body weight at the beginning of the trials (g).

[a,b,c] Means within the same row without the same superscripts are significantly different ($p<0.05$).

Table 3. Apparent digestibility of nutrients in rabbits, guinea pigs, rats and hamsters, %.

Items	Rabbits (n=10)	Guinea pigs (n=4)	Rats (n=10)	Hamsters (n=10)
Dry matter	68.5±2.57[1c]	80.5±2.00[a]	66.2±1.15[a]	72.9±1.05[b]
Crude protein	71.1±4.08[c]	79.6±2.46[a]	72.4±2.01[c]	76.3±1.86[b]
Crude fiber	21.1±6.56[b]	51.3±4.23[a]	7.4±3.77[c]	25.5±3.95[b]
NDF	30.0±5.27[c]	55.0±3.53[a]	26.1±2.71[d]	38.4±2.98[b]
ADF	23.4±6.12[b]	51.7±3.21[a]	11.2±3.16[c]	25.1±3.56[b]

[1] Mean ± SD.

[a,b,c] Means within the same row without the same superscripts are significantly different ($p<0.05$).

Table 4. Turnover time (1/k, h), transit time (TT, h) and mean retention time (MRT, h) of digesta in rabbits, guinea pigs, rats and hamsters

	Rabbits (n=4)	Guinea pigs (n=4)	Rats (n=4)	Hamsters (n=3)
1/k[2]	36.6±4.6[1a]	28.5±4.6[ab]	18.2±4.6[b]	19.8±5.3[b]
TT[3]	2.5±0.7	3.0±0.7	2.5±0.7	4.7±0.8
MRT[4]	39.1±4.5[a]	31.5±4.5[ab]	20.7±4.5[b]	23.8±5.1[b]

[1] Mean ± SD. [2] Rate-constant which is considered as a dilution rate (/h) of the marker in the pool of the digestive tract.
[3] Time-interval between feeding and first appearance of the marker in the faces. [4] Sum of 1/k and TT.
The regression line of the time-course reductions in Cr are expressed as $Y = Y_o \times e^{-kt}$; where Y is the concentration of Cr at time t, Yo is the constant depending on the level of Cr feed, k is the rate-constant and t is the time interval after feeding of the marker (h).
[a,b,c] Means within the same row without the same superscripts are significantly different ($p<0.05$).

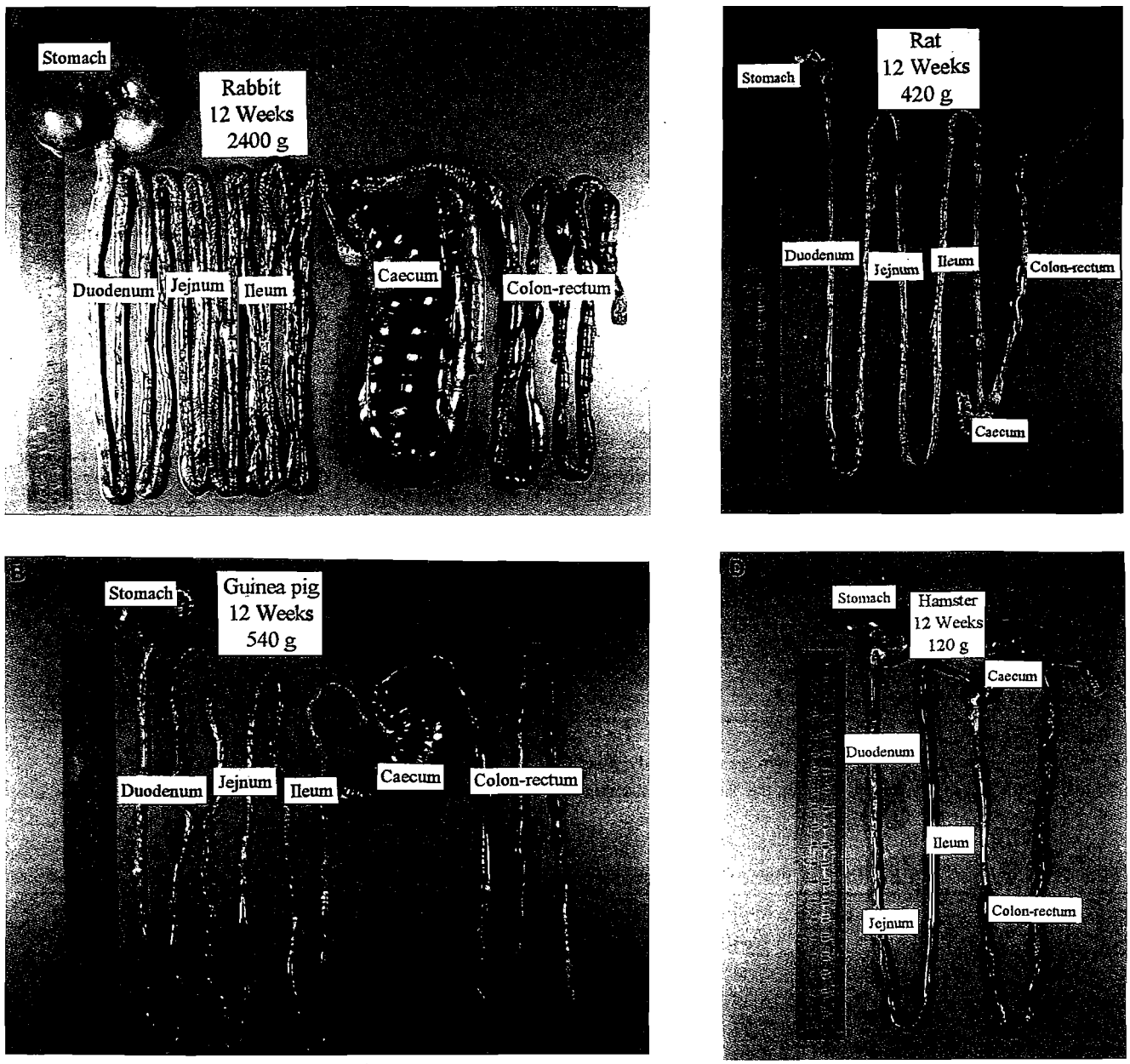

Figure 1. The anatomy of the GI tract in (A) rabbit (B) guinea pig (C) rat (D) hamster

parts of the GI tract were also noted. The relative weight and length of various segments of the GI tract differed significantly among the different animals (table 5). The relative gastric weight was the heaviest in rabbits among the four species of animals. In regard to the length of the various segments of the GI tract, the ratio of the jejunum to the entire length of the small intestine was significantly larger in rats than in the other animals. The length of the large intestine in rats was significantly shorter as compared to that in guinea pigs of the same size or hamsters of a smaller size ($p<0.05$).

From the SEM microphotographs of cecal and colonic mucosa showed in figures 2 and 3, the short dense and folded appear in the hindgut mucosa is different from the tongue-like or rod sharp villi in the mucosa of the small intestine. The folded mucosa appears primarily in the larger body sized rabbits, followed by guinea pigs. This may be related to the volume of GI tract for fermentation.

DISCUSSION

Hamsters made the lowest daily liveweight gain and ate more feed per unit of liveweight than the other animals. Rabbits made the highest daily gain and ate significantly less feed per kg of liveweight than hamsters ($p<0.05$). When intakes per unit of metabolic bodyweight ($W^{0.75}$) are compared, hamsters ate significantly less than the other animals ($p<0.05$), intakes increasing in the order guinea pigs, rabbits, and rats. The lower feed intake of hamsters per unit metabolic body mass may be attributed to its hibernation characteristic. Hamsters require less energy for maintenance, hence less food, because they hibernate in a comfortable and dim-light environment

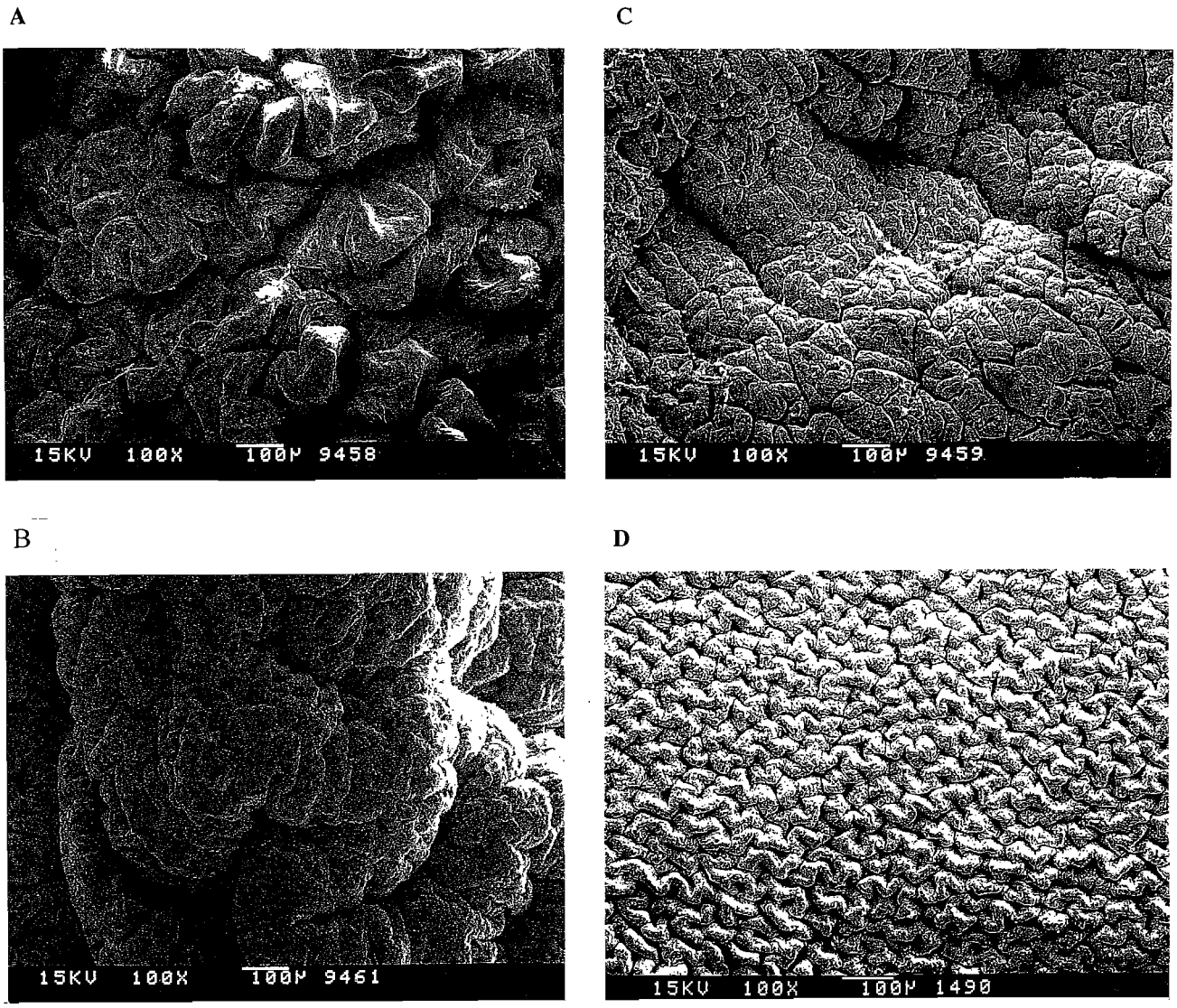

Figure 2. SEM microphotographs of caecal mucosa in (A) rabbit (B) guinea pig (C) rat (D) hamster

(Chaffee, 1966).

Both guinea pigs and rabbits possess a large semi-circular caecum volume and are strictly herbivores. The absolute weight of the caecum in rabbits was significantly heavier than guinea pigs. The relative cecal weight (per 100 g body weight) however, is lighter than in guinea pigs (table 5). The ileal-caecal valve and haustrated caecum in rabbits selectively differentiate residue according to particle size, and retains small particles with soluble matter in the caecum for further fermentation. The coarse digesta fiber residue particles are rapidly eliminated as hard (regular) feces. This rapid elimination of digesta may be attributed to the low fiber digestibility recorded in caecum fermenter rabbits (Hume and Sakaguchi, 1991). Slade and Hintz (1969) indicated that guinea pigs demonstrate better digestion of nitrogen-free-extract (NFE), crude fiber and organic matter over rabbits. Although low fibrous digestibility in rabbits, over fermentation with low fiber high concentrate diets generally results in high mortality from colitis in rabbits (Gidenne et al., 1996), implicating the significance of dietary fiber on the digestive physiology in the GI tract of rabbits.

Herbivorous hamsters on the other hand, digest NDF significantly better than rabbits, although the digestibility for crude fiber and ADF were quite similar between the two animals. This indicates that hamsters can utilize soluble fiber, as hemicellulose, better than rabbits. Since hamsters possess histologically and ultrastructurally a forestomach like the rumen in cows, they utilize fiber better (Takashi and Tamate, 1976). Our result of 38.4% NDF digestibility agreed with the result of Ehle and Warner (1978) who derived a 33.4% NDF digestibility in hamsters fed alfalfa meal.

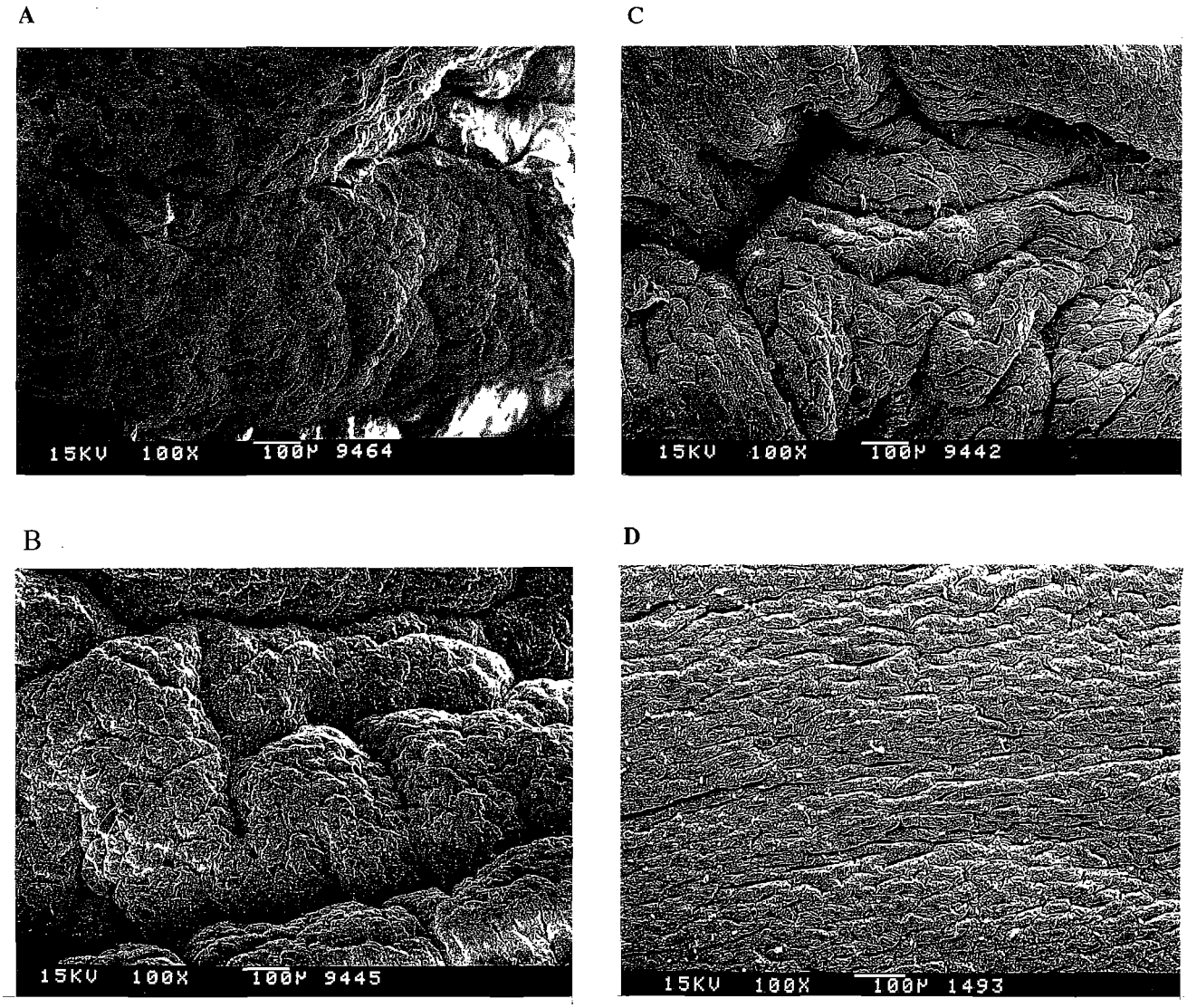

Figure 3. SEM microphotographs of colonic mucosa in (A) rabbit (B) guinea pig (C) rat (D) hamster

The retention time in the digestive tract and the level of dietary crude fiber is negatively correlated. A level of 10% dietary crude fiber is high for the omnivorous rats. The retention time or turnover time in the GI tract was significantly shorter in rats than in the three herbivores, hence a significantly lower amount of nutrients was digested, crude fiber in particular ($p<0.05$). Zhao et al. (1995) reported that rats given a high fiber diet demonstrated an increased length in the intestinal tract to compensate for the rate increase in digestive tract passage. Our data, however, did not agree with the results of Zhao et al. (1995). We found that the relative total weight of the small intestine (g/100 g live-weight) in rats did not significantly differ from that in guinea pigs and rabbits ($p>0.05$) (table 5), but was significantly heavier than that of hamsters ($p<0.05$). Conversely, the relative weight of the hindgut, which includes the caecum and colon-rectum, was significantly lighter in omnivorous rats than in the herbivores ($p<0.05$) (table 5). Rats with a shorter and lighter hindgut, exhibited a shorter mean retention time in the digestive tract. Both the weight and length ratio of the caecum to the large intestine, 78.6% and 39.4% respectively, were larger in rabbits than in the other species. Guinea pigs, on the other hand, possess the largest colon-rectum to large intestinal length ratio. This implied that the major site for hindgut fermentation was the caecum in rabbits and colon-rectum in guinea pigs.

It appears that the four laboratory animal species fed the diet with same crude fiber (10%) content, not only influenced the volume and appearance, but also the morphology of the intestinal mucosa were different among four species. Rabbits or rats produce an under-developed mucosa in the caecum due to a decreased proliferation of epithelial cells when a low fiber diet is fed to rabbits (4.5% crude fiber) (Yu and Chiou, 1996) or a crude fiber free diet is given to rats (Storme and Williams, 1981). Feeding a high fiber diet to these animals increases production of VFA from hindgut fermentation, which stimulates epithelial cell proliferation. However, animals will adapt to the prolonged ingestion of a high fiber diet by both morphological and physiological adaptation in the GI tract. Different dietary fiber components act differently upon the intestinal morphology. Supplementation of bulky insoluble fiber in the diet neither stimulated proliferation nor damaged the epithelial cells, but

Table 5. The weight and length of the gastrointestinal tract in rabbits, guinea pigs, rats and hamsters

Items	Rabbits	Guinea pigs	Rats	Hamsters
Weight, g				
Stomach	79.9 ± 18.77[1a]	7.2 ± 2.46[b]	6.6 ± 1.79[b]	2.3 ± 0.62[b]
Duodenum	10.1 ± 1.17[a]	2.8 ± 0.77[b]	1.1 ± 0.19[c]	0.7 ± 0.32[c]
Jejunum	64.7 ± 14.40[a]	13.1 ± 3.77[b]	9.5 ± 1.83[b]	1.5 ± 0.26[c]
Ileum	18.8 ± 4.09[a]	2.7 ± 0.88[b]	3.2 ± 0.35[b]	0.5 ± 0.12[c]
Caecum	148.7 ± 23.65[a]	34.5 ± 7.41[b]	7.0 ± 1.32[c]	3.8 ± 0.72[c]
Colon-rectum	40.4 ± 8.32[a]	18.6 ± 4.14[b]	6.1 ± 2.1[c]	3.3 ± 0.78[c]
Relative weight, g/100g body weight				
Stomach	4.1 ± 1.04[a]	1.9 ± 0.52[b]	2.4 ± 0.91[b]	2.0 ± 0.52[b]
Small intestine				
Duodenum	0.5 ± 0.09[b]	0.8 ± 0.21[a]	0.4 ± 0.08[b]	0.6 ± 0.24[b]
Jejunum	3.4 ± 0.85[a]	3.5 ± 0.87[a]	3.2 ± 0.38[a]	1.3 ± 0.22[b]
Ileum	1.0 ± 0.23[a]	0.7 ± 0.27[b]	1.1 ± 0.25[a]	0.4 ± 0.08[c]
Total weight	4.9 ± 1.08[a]	5.0 ± 0.96[a]	4.7 ± 0.64[a]	2.3 ± 0.29[b]
Hindgut				
Caecum	7.8 ± 1.74[b]	9.2 ± 1.70[a]	2.4 ± 0.35[c]	3.2 ± 0.53[c]
Colon-rectum	2.1 ± 0.58[c]	4.9 ± 0.67[a]	2.0 ± 0.51[c]	2.8 ± 0.62[b]
Total weight	9.9 ± 2.18[b]	14.1 ± 1.90[a]	4.4 ± 0.58[d]	6.0 ± 0.86[c]
Length, cm				
Duodenum	40.5 ± 3.78[a]	24.5 ± 9.18[b]	7.8 ± 2.05[c]	11.1 ± 3.96[c]
Jejunum	206.1 ± 24.66[a]	106.5 ± 8.31[b]	93.2 ± 6.86[c]	21.1 ± 4.89[d]
Ileum	61.6 ± 6.22[a]	29.5 ± 2.07[b]	25.2 ± 1.94[c]	8.3 ± 0.67[d]
Caecum	63.8 ± 4.49[a]	11.3 ± 1.16[b]	4.9 ± 0.85[d]	7.3 ± 0.82[c]
Colon-rectum	98.5 ± 9.55[a]	86.8 ± 4.66[b]	18.8 ± 2.90[d]	34.5 ± 3.08[c]

[1] Mean ± SD (n=10).

[a,b,c,d] Means within the dame row without the same superscripts are significantly different ($p<0.05$).

increased rate of digesta passage (Sircar et al., 1983). The provision of pectin or lignin in the diet, however, significantly increased epithelial cell multiplication in the intestinal mucosa (Yu and Chiou, 1996). The crude fiber was supplemented using alfalfa and was only 10% in this experiment. This therefore did not result in damaged mucosa in this trial.

CONCLUSION

A diet of 10% dietary fiber or cell wall did not result in damaged mucosa in these growing animals. Rabbits attained the heaviest daily live-weight gain while guinea pigs grew the most rapidly with the best rate of live-weight gain. Rabbits utilized feed significantly more efficiently than rats and hamsters ($p<0.05$), because rabbits are economical domesticated animals. Guinea pigs also showed better feed conversion rates than rats and hamsters. Rabbits exhibited the longest retention time of digesta. Guinea pigs on the other hand, showed the significantly longest colon-rectum and the highest ability in the digestion of crude fiber, NDF and ADF ($p<0.05$). Omnivore rats showed significantly poorer digestion of dry matter and fibrous components than the herbivores. This may be attributed to the lighter relative weight of hindgut in rats.

ACKNOWLEGEMENTS

The authors thank the National Science Council of Taiwan for financial support for this project. The project number is NSC 83-0409-B-005-075.

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