Digestion of Fibrous Fractions from Plant Materials in the Gastrointestinal Tract of the Ruminant

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Abstract

Studies on fiber digestion from plant materials in ruminants have placed emphasis on the process of degradation in the rumen. Cellulose appears to be essentially 100% degradable in the rumen irrespective of feeding regimen, provided it is in the pure state. Degradation of fiber fractions from plant materials in the rumen decreased to 40 to 50%, presumably due to the presence of pentoses such as xylose and arabinose in these materials. Particle size reduction associated with the ruminal retention time of feed particles may be involved in the degree of fiber degradation in the rumen, though this factor has been found to be of minor importance. Degradation of fiber fractions from plant materials occurs also in the post-ruminal digestive tract. The cecum contributed about 20% of fiber digestion in the gastrointestinal tract and the contribution of the rumen was estimated to be about 80%. The pattern of mass base frequency of digesta particles was found to be similar in the omasal and rectal contents and no significant difference was observed in the average diameter of the particles in the omasal and rectal contents. The pattern of particle distribution in feces may provide useful information for predicting the degradation of fibrous fractions from plant materials in the rumen.

Introduction

Plants produce a large amount of carbohydrates in the world, of which only small portions are able to supply directly available energy for human beings in the form of cereals. A large proportion of aerial parts of plants consists of a fiber-rich fraction that cannot be utilized as human food resources without processing it to degrade its β-configuration. Herbivorous animals are known to be able to process fibrous materials from plants, especially ruminants are the most effective animals in utilizing fibrous materials due to the structure of their digestive system (Fujikura *et al.*, 1989). The digestion or degradation of fibrous materials by ruminants is characterized by the fermentation of plant materials in the rumen. Thus, ruminants are categorized as fore-gut fermenters (Hume and Warner, 1980). In nutrition studies on ruminants, investigations have been concentrated on the mechanisms of fermentation in the rumen, size reduction of feed particles and their passage rates, and little attention has been paid to the post-ruminal digestion of fibrous fractions. Thus, the present paper intended to discuss the significance of fiber digestion in the rumen and the post-ruminal tract.

Degradation of fibrous fractions in the rumen

1 Cellulose degradation

Cellulose degradation in the rumen appeared to reach a potential value of 100% when

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determined under feeding regimens with various ratios of concentrate to grass or legume hay (Sekine, 1991). The concentrate for fattening beef was mixed with Italian ryegrass hay or alfalfa hay in the ratios of 0 : 100, 30 : 70, 60 : 40 and 85 : 15 and was given to sheep at the maintenance level. Cellulose degradation was determined by *in situ* technique and degradation kinetics was calculated using a simple order kinetic equation with discrete lag time as described by Mertens and Loften (1980). The digestible fraction of cellulose was almost 100% when it was estimated from the results obtained for ryegrass and alfalfa diets (Table 1). The digestion rate constant did not change appreciably in ryegrass diets with ratios of 0 : 100 to 60 : 40 and tended to decrease in the ratio of 85 : 15, while in alfalfa diets it tended to be higher in the ratio of 0 : 100 than in the others and to be lower in the ratios of 60 : 40 and 85 : 15.

Table 1 Digestible fraction (D_0), digestion rate (k), lag time (LT), digestibility for 24 h incubation (D_{24}) of cellulose determined for various feeding regimens

Dietary treatment	D_0, %	k, h^{-1}	LT, h	D_{24}, %
Concentrate : Italian ryegrass hay				
0 : 100	100.0	0.027	0.0	47.2
30 : 70	100.0	0.026	2.0	43.5
60 : 40	87.7	0.029	− 0.9	45.4
85 : 15	100.0	0.014	− 7.9	35.2
Concentrate : Alfalfa hay				
0 : 100	87.2	0.059	− 2.1	68.4
30 : 70	100.0	0.022	−11.9	53.8
60 : 40	100.0	0.011	−41.2	49.0
85 : 15	100.0	0.016	−22.3	51.2

Table 2 Chemical composition of feedstuffs and estimated composition of diets

	DM	OM	CP	NDF	HC	ADF	ADL	CC
	%	% DM						
Italian ryegrass hay	87.6	80.9	12.8	61.1	21.9	39.2	4.5	38.9
Alfalfa hay	85.9	90.2	21.5	36.4	6.4	30.0	6.3	63.6
Formula feed	89.0	94.7	14.4	13.6	7.7	5.9	1.4	86.4
Concentrate : Hay								
Ryegrass diet								
30 : 70		85.0	13.2	46.2	17.0	29.2	3.6	53.8
60 : 40		89.2	13.7	32.4	13.2	19.2	2.7	67.6
85 : 15		92.7	14.1	20.7	9.8	10.9	1.9	79.3
Alfalfa diet								
30 : 70		90.2	19.3	29.2	6.4	22.8	4.8	70.8
60 : 40		92.9	17.2	22.6	7.0	15.6	3.4	77.4
85 : 15		94.0	15.4	17.0	7.5	9.5	2.1	83.0

Note : Abbreviated notations are as follows ; DM, dry matter ; OM, organic matter ; CP, crude protein ; NDF, neutral detergent fiber ; HC, hemicellulose ; ADF, acid detergent fiber ; ADL, acid detergent lignin ; CC, cellular contents.

Nitrogen concentration in the alfalfa diet with the ratio of 0 : 100 was the highest among the diets used in this study. The concentrations of nitrogen and cellular contents in the diets were similar among the alfalfa diets with ratios of 60 : 40 and 85 : 15, and the ryegrass diet with the ratio of 85 : 15 (Table 2). Taniguchi *et al.* (1984 and 1986) demonstrated that an increased ingestion of starch resulted in the decrease of the digestion of cellulose in the whole digestive tract of sheep with a constant level of nitrogen supply and that an increased ingestion of nitrogen increased the digestion of cellulose in the whole tract of steers with a constant supply of readily digestible carbohydrates. Thus, the rate of cellulose degradation appeared to be influenced by the supply of nitrogen and readily fermentable fractions in a diet.

2 Degradation of plant fiber complex

Degradation of fibrous fractions in the rumen was somewhat different from that of pure cellulose. The degradation pattern of neutral detergent fiber (NDF) from Italian ryegrass hay or alfalfa hay appears to differ depending on the feeding regimens (Sekine, 1990). Table 3 shows the digestion kinetics of NDF in Italian ryegrass hay, alfalfa hay and formula feed incubated in the rumen of sheep given diets with various ratios of concentrate to hay. The NDF of ryegrass hay was degraded at a fairly high rate under the feeding of a ryegrass diet with the ratio of 0 : 100, while the inclusion of concentrate in the diet decreased the

Table 3 Digestible fraction (D_0), digestion rate (k), lag time (LT) and digestibility for 24 h incubation (D_{24}) of NDF in Italian ryegrass hay, alfalfa hay and formula feed determined for various feeding regimens

Dietary treatment	D_0, %	k, h^{-1}	LT, h	D_{24}, %
Concentrate : Italian ryegrass hay				
		Italian ryegrass hay		
0 : 100	48.1	0.130	9.5	40.8
30 : 70	52.8	0.031	3.3	25.1
60 : 40	44.3	0.049	4.5	27.3
85 : 15	25.6	0.081	20.3	6.6
		Formula feed		
0 : 100	100.0	0.022	13.6	21.6
30 : 70	79.4	0.006	− 9.6	14.2
60 : 40	100.0	0.010	− 6.2	24.9
85 : 15	90.8	0.006	− 2.0	13.9
Concentrate : Alfalfa hay				
		Alfalfa hay		
0 : 100	41.1	0.066	6.0	28.6
30 : 70	53.3	0.028	6.0	21.3
60 : 40	34.1	0.106	20.5	10.7
85 : 15	100.0	0.009	13.5	8.6
		Formula feed		
0 : 100	69.1	0.038	− 4.9	47.2
30 : 70	100.0	0.016	− 7.3	39.4
60 : 40	86.6	0.005	−41.7	22.5
85 : 15	100.0	0.010	−13.1	30.2

degradation rate (k) of NDF of ryegrass hay. Feeding of a diet with the ratio of 85 : 15 decreased the degradation of NDF for 24 h (D_{24}) with a prolonged discrete lag time (LT) compared with the other feeding regimens. For the NDF of alfalfa hay, the k value was half of that of ryegrass hay under the feeding of alfalfa diet with the ratio of 0 : 100 and D_{24} was 28.6%. The k value under the other feeding regimens tended to decrease with the inclusion of concentrate in the diet, with somewhat contradictory results in the diet with the ratio of 60 : 40. The D_{24} decreased to about 10% under the feeding of alfalfa diets with ratios of 60 : 40 and 85 : 15, along with the prolongation of LT. Potential degradation of NDF ranged from 40 to 50% under the feeding of ryegrass diets with ratios of 0 : 100, 30 : 70 and 60 : 40, and alfalfa diets with ratios of 0 : 100 and 30 : 70. Digestion rates of NDF in the formula feed were lower than those of grass and legume hays and decreased with the inclusion of concentrate in the diets. The decrease in the digestion rate was greater in the NDF of formula feed than in hays. The NDF of formula feed contained more hemicellulose and ADL, and fewer cellulose fractions than those of hays. The constituents of NDF may partly be responsible for the lower digestion rate of NDF in the formula feed. Estimates for D_{24} were higher in feeding of alfalfa diets than of ryegrass diets. This discrepancy may be caused by the difference in the concentration of nitrogen in diets given to sheep during the *in situ* determination. Potential degradation of NDF was not simply related to the ratio of the structural carbohydrate and non-structural carbohydrate in a diet, but the rate of NDF degradation was negatively affected by the xylose to arabinose ratio, the proportions of xylose in NDF and arabinose in dry matter (Varga and Whitsel, 1991). Degradation rates of NDF in various cereal straws were almost similar when determined *in situ* under the same feeding regimen (Wanapat *et al*., 1989). Substances containing phenolic monomers impaired the degradation of fibrous fractions in the rumen (Ushida *et al*., 1988). The rate of NDF degradation appeared to be affected by the concentrations of its constituents and the feeding regimen. Thus, the potential degradation of fibrous fractions from plant materials in the rumen appears to decrease with the concentrations of constituents such as xylose, arabinose and phenolic monomers in hemicellulose and lignin.

Obviously, the degradation of fibrous fractions in the rumen is a time-dependent process. Thus, the degradability of fibrous fractions in the rumen may be affected by the outflow rate of digesta and the rate of particle size reduction.

Passage rate of digesta

The outflow rate of digesta from the rumen was affected by the changes in the ratio of concentrate to hay (Sekine, 1991). When sheep were given Italian ryegrass hay mixed with concentrate, the digesta outflow rate increased from 0.025 h^{-1} for a diet with hay only, to about 0.033 h^{-1} for mixed diets. For alfalfa diets, the inclusion of concentrate in a diet decreased the passage rate from 0.037 h^{-1} to 0.022 h^{-1} as the proportion of concentrate increased. Passage rate of digesta through the gastrointestinal tract was estimated to be 0.021 h^{-1} based on the excretion rate of feces for goats fasted for 7 days after being fed Italian ryegrass hay (Sekine, unpublished). This observation agrees well with the results obtained by the chromium index method described above. Degradation of dry matter in the rumen for a diet determined by incubation for the time equivalent to the rumen retention time obtained from the reciprocal of the passage rate was positively correlated with the effective degradability of dry matter for the corresponding diet (Mir *et al*., 1991). Thus, the potential degradability of NDF in diets given to sheep was estimated from the results obtained in the *in situ* experiment, the ratio of concentrate to hay and content of NDF in each feedstuff. Results are presented in Table 4 together with the results of NDF digestibility determined by the total collection method. Digestibilities of NDF for ryegrass diets were consistently higher in the estimated potential degradability than in the determined one except for the diet with

Table 4 Comparison between the potential digestibility of dietary NDF estimated from the result obtained in *in situ* determination and that determined by the total collection method

	Concentrate ratio							
	ryegrass diet				alfalfa diet			
	0	30	60	85	0	30	60	85
NDF digestibility determined, %	49.7	42.9	35.3	34.1	52.2	48.2	53.2	60.0
Potential digestibility estimated, %	48.1	55.9	58.6	62.2	41.1	60.5	53.3	100.0

hay only. The NDF digestibility decreased as the proportion of concentrate increased. This decrease in digestibility may be caused by an increase in the passage rate, even though the post-ruminal degradation of NDF occurred to some extent (Taniguchi, 1991). On the other hand, for alfalfa diets the difference between NDF digestibilities determined and the estimated potential was inconsistent, though the passage rate decreased as the proportion of concentrate increased. Taniguchi (1991) demonstrated that NDF in alfalfa meal was degraded in the post-ruminal tract to a greater extent irrespective of the proportion of concentrate in a diet. The post-ruminal degradation of NDF in alfalfa diets may have compensated for the decreased degradation in the rumen.

Rate of particle size reduction in the rumen

Distribution of acid detergent fiber (ADF) and acid detergent lignin (ADL) was determined in the reticulo-rumen, omasum, abomasum, small intestine (duodenum, jejunum and ileum), cecum and large intestine (colon and rectum) of sheep given orchardgrass hay once a day (Sekine, 1991). Changes with the time after feeding of the quantity of ADF and ADL in four sieved fractions are shown in Fig. 1 and 2 on the basis of intakes of the corresponding composition for each site of the digestive tract. Quantities of ADF and ADL did not change significantly with the time after feeding in any sites of the tract except for the reticulo-rumen. Particle fractions with particles larger than 1180 μm (large particles, LP) of ADF and ADL in the reticulo-rumen were greater at 2 h after feeding than at 24 h ($P<0.01$) and tended to decrease as the time elapsed after feeding. The other fractions (300–1180, medium particles, MP, 45–300, small particles, SP, and less than 45 μm, fine particles and liquid, FPL) did not change appreciably with the time after feeding. Since the proportion of LP of ADF and ADL in the reticulo-rumen decreased with the time after feeding, the proportion of the sum of MP, SP and FPL increased with the time after feeding (Fig. 3 and 4). On the other hand, the proportions of particle fractions in the post-ruminal tract did not change appreciably with the time after feeding irrespective of the size of the particles (Fig. 3 and 4). Proportions of LP fraction of ADF and ADL were significantly greater in the reticulo-rumen than in any other sites of the digestive tract irrespective of the time after feeding ($P<0.01$). The proportion of the LP fraction did not differ significantly among the omasum, abomasum, cecum and large intestine ($P>0.05$).

The reduction in the quantity or proportion of LP fraction in the reticulo-rumen may be ascribed to the digestion in the reticulo-rumen and physical processes such as mastication (Sekine, 1991). The time required for chewing (T, min) increased with the time after feeding, and was negatively correlated with the LP fractions of NDF, ADF and ADL in the reticulo-rumen (LP, g/g intake) ($P<0.01$). The following regression equations were obtained :

NDF ; $LP=1.41-0.0028(\pm 0.0003)T$, $r=-0.87$, s. e. ± 0.04,
ADF ; $LP=1.45-0.0029(\pm 0.0004)T$, $r=-0.86$, s. e. ± 0.05,
ADL ; $LP=1.54-0.0028(\pm 0.0005)T$, $r=-0.81$, s. e. ± 0.06.

Coefficients of determination were calculated to be about 0.7 for all the equations. Thus, 70% of the variation in the LP fraction may be ascribed to the changes in the chewing time. The recovery of ADL was over 98% of the amount ingested in the results of digestion trial. Thus,

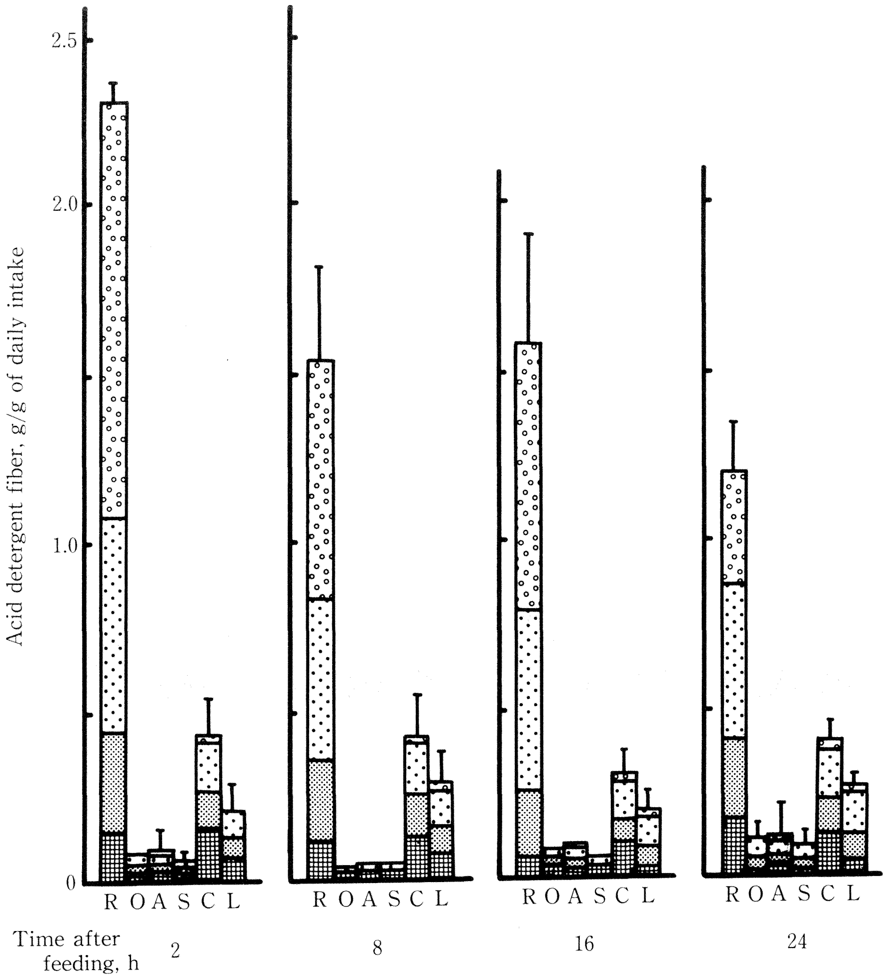

Fig. 1 Changes with the time after feeding in acid detergent fiber of four sieved fractions (▢ > 1180 μm, ▢ 300-1180, ▢ 45-300, ▢ < 45 μm) on the basis of the intake (g/g) for the reticulo-rumen (R), omasum (O), abomasum (A), small intestine (S), cecum (C) and large intestine (L) of sheep.
Vertical lines indicate the standard deviation.

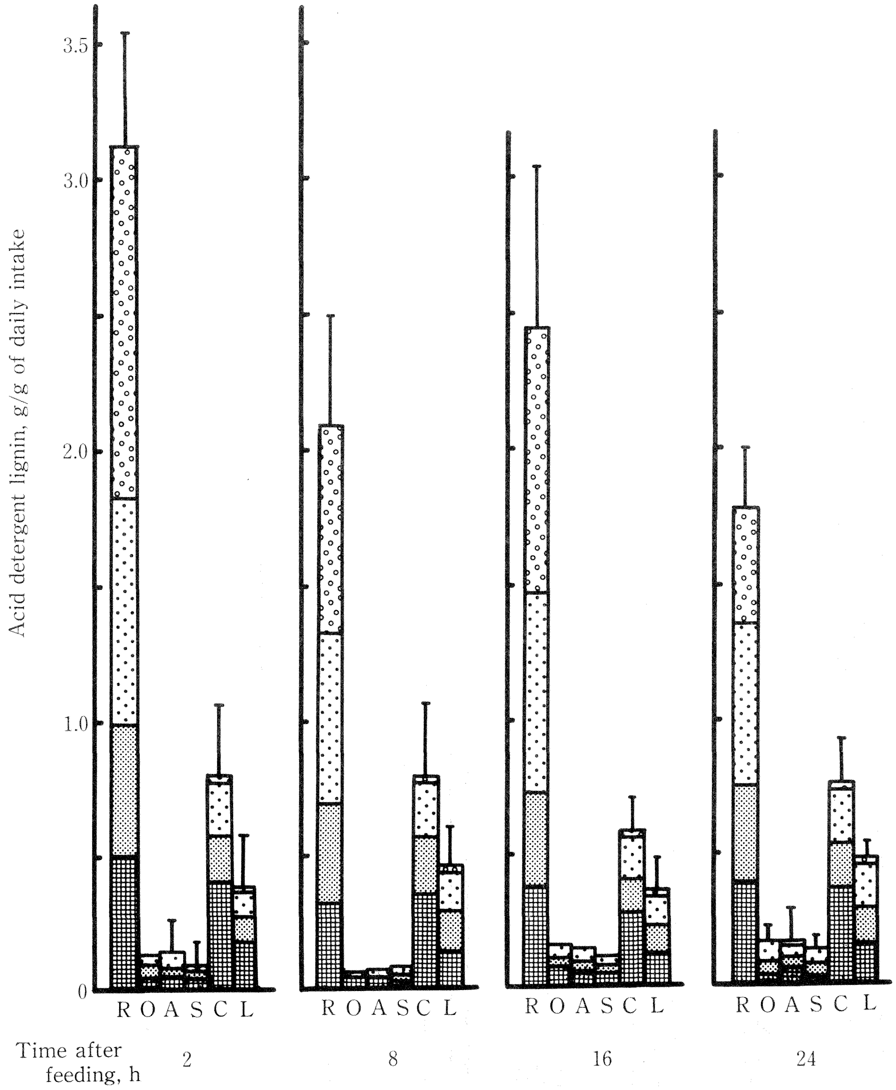

Fig. 2 Changes with the time after feeding in acid detergent lignin of four sieved fractions (> 1180μm, 300–1180, 45–300, <45μm) on the basis of the intake (g/g) for the reticulo-rumen (R), omasum (O), abomasum (A), small intestine (S), cecum (C) and large intestine (L) of sheep.
Vertical lines indicate the standard deviation.

it was assumed that the ADL fraction was not affected by the digestion. Regression coefficients for NDF, ADF and ADL were approximately identical. Disappearance rates of the LP fraction for DM, NDF, ADF and ADL (LP_{DM}, LP_{NDF}, LP_{ADF}, and LP_{ADL}, g/g intake) were estimated to be 0.030, 0.035, 0.036 and 0.033 h^{-1}, respectively. Disappearance rates of LP

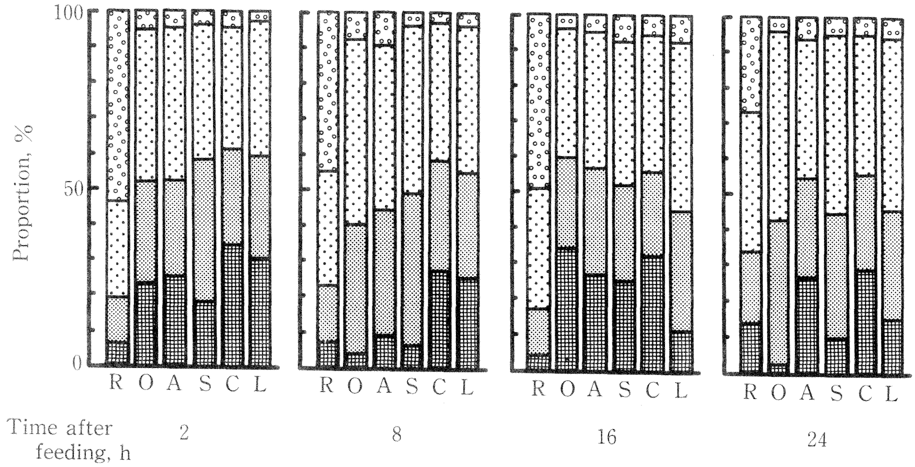

Fig. 3 Changes with the time after feeding in the proportion of acid detergent fiber of four sieved fractions (> 1180μm, 300–1180, 45–300, <45μm) for the reticulo-rumen (R), omasum (O), abomasum (A), small intestine (S), cecum (C) and large intestine (L) of sheep.

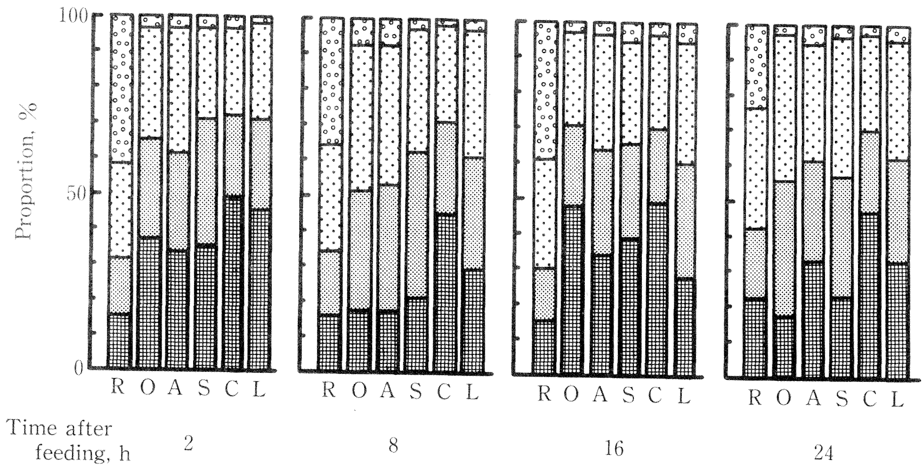

Fig. 4 Changes with the time after feeding in the proportion of acid detergent lignin of four sieved fractions (> 1180μm, 300–1180, 45–300, <45μm) for the reticulo-rumen (R), omasum (O), abomasum (A), small intestine (S), cecum (C) and large intestine (L) of sheep.

fractions for NDF and ADF were slightly higher than that for ADL, which may indicate the extent of the contribution of the digestion process to the degaradation of the fibrous fractions. Physical processes such as remastication during rumination, therefore, are considered to exert a greater influence on the particle size reduction in the case of large particles of fibrous fractions than the digestion process in the reticulo-rumen. McLeod and Minson (1988) observed that mastication and rumination contributed to 75% of the size reduction of particles larger than 1180 μm in the rumen of cattle given ryegrass or alfalfa hay. Kennedy (1985) reported that a bolus regurgitated from the rumen of steers given grass or legume hays contained 61.0% of particles larger than 3.35 mm while that reswallowed after rumination contained 17.3% of such particles. Thus, it is estimated that for 72% of the larger particles the size was reduced through rumination. A physical process such as mastication contributes about two thirds of the size reduction of large particles in the reticulo-rumen and the digestion process is estimated to play a less important role in particle size reduction. The distribution and pool size of the MP, SP and FPL fractions were not influenced by the time after feeding. Pools for these fractions appeared to maintain an equilibrium between the inflow from a pool of larger particles than those of a given fraction and outflow to a pool of smaller particles than those of the corresponding fraction and/or to the post-ruminal tract.

Degradation of fibrous fractions in the post-ruminal tract

The mean inflow and outflow of ADL to a given site of the digestive tract (wt, h^{-1}) were assumed to be the same as the mean rate of ADL intake per hour which can be estimated from the daily ADL intake divided by 24, since the amount of ADL distributed did not differ with the time after feeding in any site of the tract (Fig. 2). Then, the mean retention time for each site of the tract (RT_X, h) was estimated using the mean ADL pool determined in a given site of the tract (Wt_x) as follows : $RT_X = (Wt_x/wt)$. Furthermore, the mean ADL pools of LP, MP, SP and FPL fractions in each site of the tract were expressed as W_i. Assuming the proportions of LP, MP, SP and FPL fractions of ADL escaping from the reticulo-rumen are the same as those in the omasum and abomasum, or those from the cecum are the same as those in the large intestine (d_i) due to the absence of significant differences in the proportional distribution of the four fractions among the omasum, abomasum and large intestine, the rate constants (k_i) of each fraction in the reticulo-rumen and cecum were estimated using the following equation : $k_i = (wt \cdot d_i)/W_i$. Table 5 shows the estimates of mean retention time for each site of the tract and of rate constants for each fraction in the reticulo-rumen and cecum. Feed particles were estimated to require about 93 h for passing through the digestive tract of sheep. The RT of the reticulo-rumen accounted for more than 60% of RT for the whole tract and RT for the cecum and large intestine accounted for 30%

Table 5 Mean retention time (MRT, h) of digesta in various sites of the digestive tract and mean passage rate constants (k, h^{-1}) for LP, MP, SP and FPL fractions in the reticulo-rumen and cecum

	MRT, h	k (h^{-1}) for the fraction of			
		LP	MP	SP	FPL
Reticulo-rumen	57.0±15.8	$0.004^a \pm 0.002$	$0.023^b \pm 0.008$	$0.032^b \pm 0.010$	$0.032^b \pm 0.013$
Omasum	2.9±1.5				
Abomasum	3.1±2.5				
Small intestine	2.5±1.5				
Cecum	17.6±5.0	$0.086^c \pm 0.053$	$0.076^c \pm 0.022$	$0.079^c \pm 0.026$	$0.044^d \pm 0.015$
Large intestine (colon and rectum)	10.0±3.4				

Note : Figures with different superscripts in the same row are significantly different ($P<0.01$).
Sizes of particle fractions are presented in the text.

of the total. The passage of feed particles through the digestive tract is determined by the rate of passage through the reticulo-rumen, cecum and large intestine. The passage rate constant for the LP fraction was significantly lower than that for the rest of the fractions in the reticulo-rumen, while the corresponding value for the FPL fraction was significantly lower than that for the others in the cecum. Poppi *et al.* (1980) demonstrated that the critical size of a feed particle to pass through the rumen of sheep was 1.18 mm irrespective of the kinds of hay or growth stages of the plant. Kerley *et al.* (1985) observed that the critical size to pass through the rumen of sheep consuming forages *ad libitum* ranged from 0.6 to 0.7mm. Sakaguchi and Hume (1989) showed that ring-tail possums and rabbits selectively retained fine particles and liquid in the cecum for fermentation. It was suggested that the reticulo-omasal orifice was responsible for the limitation of the flow of the LP fraction to the omasum (Fujikura *et al.*, 1990). The reticulo-rumen selectively retains the LP fraction through the reticulo-omasal orifice and the cecum selectively retains the FPL fraction to promote fermentation by microorganisms.

To determine whether fibrous fractions were digested in various sites of the alimentary tract, cumulative digestibilities of ADF in various sites of the tract were estimated using ADL as an index. Digestibility of ADF in the reticulo-rumen (D_{ADF}, %) increased with the time after feeding (T, h) and the following regression equation was obtained : $D_{ADF} = 22.3 \cdot T^{0.126}$. The time after feeding did not affect appreciably the estimated digestibility of ADF in the other sites of the tract. Estimated digestibilities of ADF did not differ significantly in

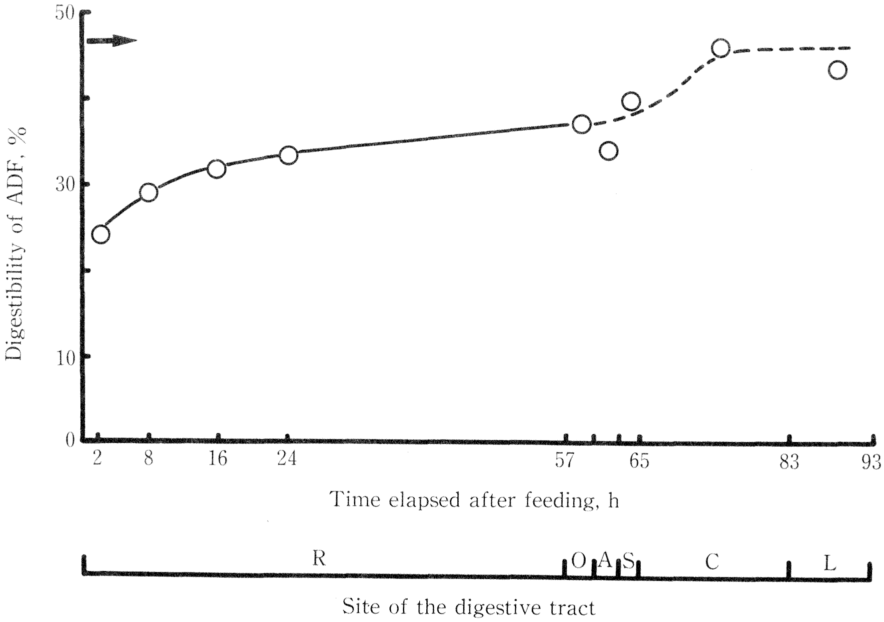

Fig. 5 Digestibility of acid detergent fiber in the reticulo-rumen (R), omasum (O), abomasum (A), small intestine (S), cecum (C) and large intestine (L) in conjunction with mean retention time for each site of the tract.

The arrow shows ADF digestibility determined by the digestion trial. Solid line is drawn by the regression equation ; $Y=22.3X^{0.126}$ and broken line by inspection.

the omasum, abomasum and small intestine, but were greater significantly in the cecum and large intestine than in the other sites. Estimated digestibilities of ADF in the cecum and large intestine were similar and agreed well with the digestibility determined in the digestion trial. Estimated ADF digestibility increased by 8% units in the cecum from that in the small intestine. The ADF in barley, barley by-product of integrated alcohol-starch production and wheat mill run was degraded by 8.6, 11.3 and 9.3% in the post-ruminal tract and NDF by 11.9, 12.1, and 9.9%, respectively (Aronen *et al.*, 1991). The NDF in cereal straws was degraded in the range of 5.1 to 9.6 in the post-ruminal tract (Wanapat *et al.*, 1989). Cumulative ADF digestibilities in various sites of the digestive tract were plotted in conjunction with RT for each site of the tract (Fig. 5). Assuming that the results obtained in the cecum and large intestine corresponded to the digestibility of the whole tract, ADF digested in the reticulo-rumen for 57 h contributed to 80% of the digestion in the whole tract and 20% in the cecum, while the contribution of ADF digestion was negligible in the omasum, abomasum, small intestine and large intestine. The digestion in the cecum accounted for almost all the fibrous fractions degraded in the post-ruminal tract.

Mean particle size and particle distribution pattern in digestive tract

Quantities and proportions of particles with various sizes showed fairly similar distribution patterns in the post-ruminal tract except for the small intestine (Fig. 1 to 4). These results indicate that the particle size distribution in the omasum or abomasum reflects that in the large intestine, which in turn, reflects that in the feces. Determination of particle size distribution in the feces may provide a fair amount of information about the digestion of fibrous fractions in the reticulo-rumen and the whole digestive tract. The particle size distribution, however, provides limited information about the accurate size of particulates of digesta moving along the digestive tract. The size of particulates in digesta in various sites of the tract was determined using an image analyzer as Heywood's diameter of a particle, which is equivalent to the diameter of a circle equal in size to the projected area of a given particle. Mass base frequency distributions of the particles were calculated for digesta in various sites of the tract of cattle, sheep and goats (Fig. 6, 7 and 8) (Sekine, 1991). The pattern of mass base frequency distributions of the particles was similar for the omasum, abomasum, small intestine, cecum, colon and rectum irrespective of animal species. Average Heywood's diameter was the greatest in the reticulo-rumen and the value decreased to about one half in the omasum for cattle or to a third for sheep and goats. The diameter stayed at a constant level in the lower gut irrespective of animal species. These results indicate the absence of a substantial particle size reduction in the post-ruminal tract and the fact that the fecal particle distribution reflects that in the post-ruminal tract. The pattern of mass base frequency distribution for particles in the reticulo-rumen deviated to more than 1 mm of Heywood's diameter irrespective of animal species. The pattern for goats showed the presence of particles larger than 10 mm in diameter and the pattern for sheep showed that the particles were less than 5 mm in diameter. Sheep and goats were given the same ryegrass hay and were slaughtered at 2 hours after feeding. As a result, the animals may have had a limited time to ruminate. This difference in the distribution pattern suggests that mastication at the time of ingestion of feed is different between sheep and goats. The pattern of mass base frequency distribution in the post-ruminal tract was similar both in sheep and goats. Results for the post-ruminal tract of cattle also showed a similar pattern to that for sheep and goats, though in cattle the average Heywood's diameters of the particles were greater. These findings suggest that the animals display a similar rumination efficiency for particle size reduction with different critical sizes of particles to pass through the reticulo-omasal orifice.

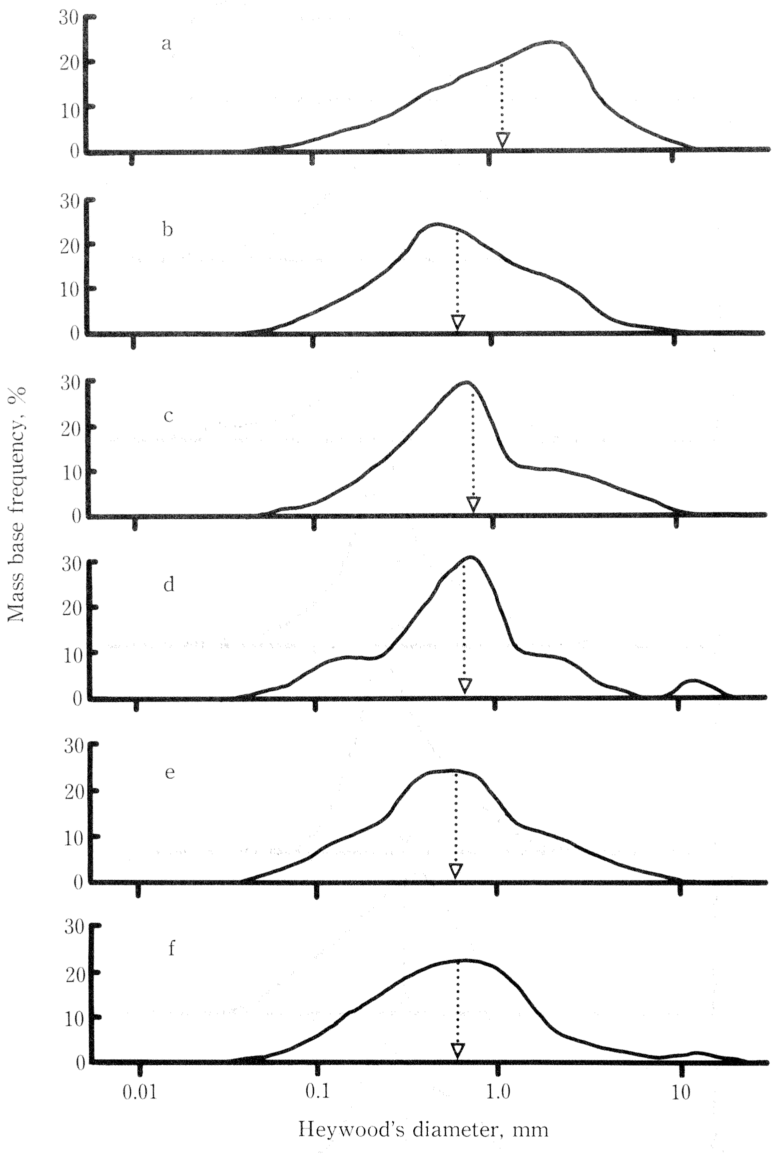

Fig. 6 Patterns of mass base frequency distribution of particles of digesta in the reticulo-rumen (a), omasum (b), abomasum (c), small intestine (d), cecum and colon (e) and rectum (f) of cattle slaughtered at 40 h after feeding of the diet consisting of 77% of concentrate and 23% of Italian ryegrass hay.
Dotted lines with open triangles indicate average Heywood's diameter of particles.

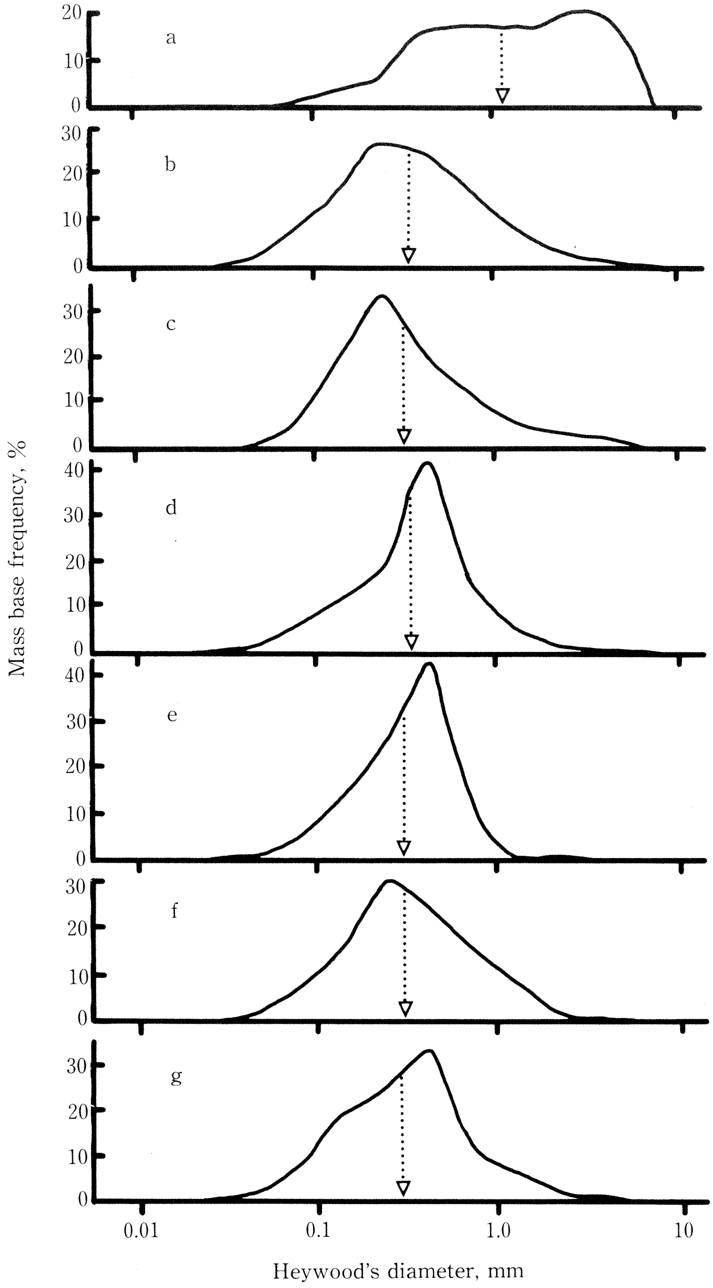

Fig. 7 Patterns of mass base frequency distribution of particles of digesta in the reticulo-rumen (a), omasum (b), abomasum (c), small intestine (d), cecum (e), colon (f) and rectum (g) of sheep slaughtered at 2 h after feeding of Italian ryegrass hay.
Dotted lines with open triangles indicate average Heywood's diameter of particles.

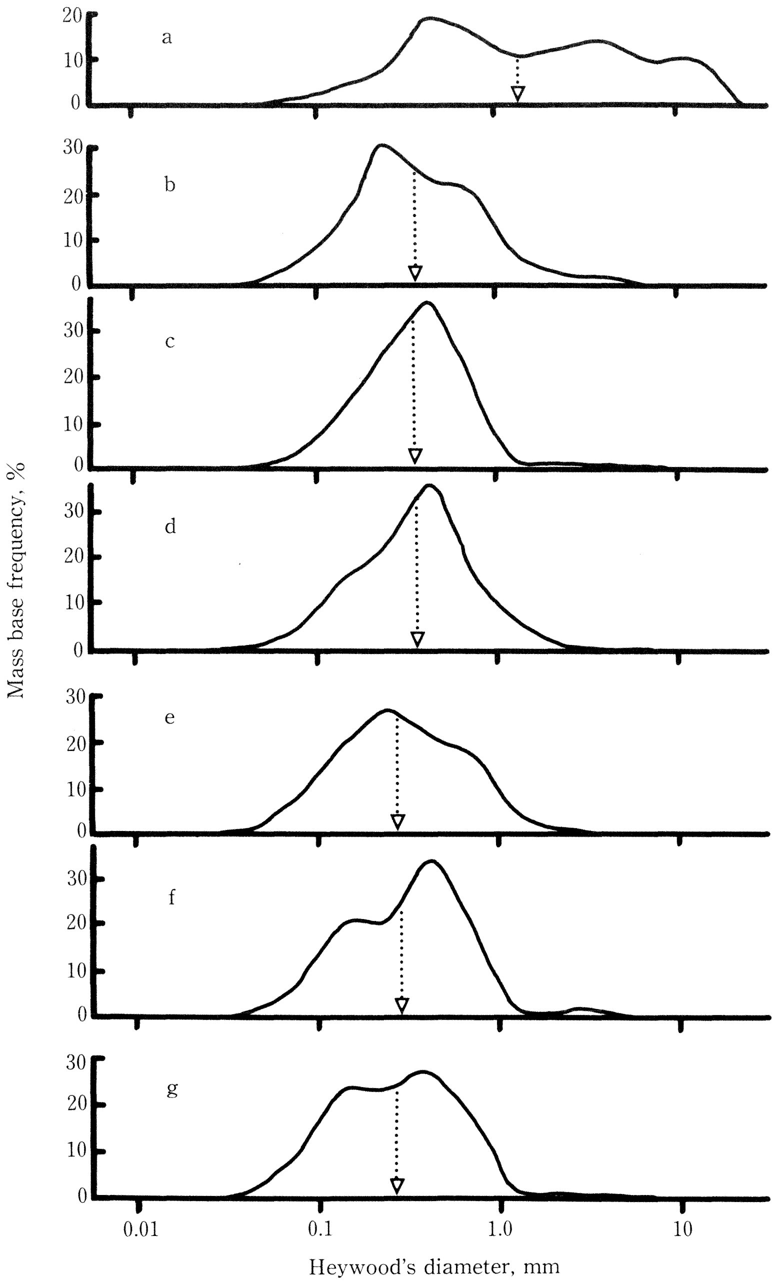

Fig. 8 Patterns of mass base frequency distribution of particles of digesta in the reticulo-rumen (a), omasum (b), abomasum (c), small intestine (d), cecum (e), colon (f) and rectum (g) of goat slaughtered at 2 h after feeding of Italian ryegrass hay.

Dotted lines with open triangles indicate average Heywood's diameter of particles.

Conclusion

Pure cellulose is potentially 100% digestible, but its degradation rate is affected by the supply of nitrogen and readily fermentable fractions in the rumen. Degradation of NDF from plant materials is limited by some intrinsic barriers to fermentation such as the presence of xylose, arabinose or phenol monomers. Thus, the potential degradability decreases to about 50%. Although the degradation of the fibrous fractions in the rumen also decreases as the ruminal outflow rate increases, the digestibility for the whole tract may be compensated by fermentation in the lower gut to some extent in the case of grass hay and to a larger extent in the case of legume hay. This compensation is not caused by the size reduction of feed particles in the post-ruminal degradation, but the fermentation of fine particles in the cecum may be responsible for this phenomenon. Therefore, the particle distribution in feces reflects the extent of particle size reduction in the rumen. Mastication is the major factor contributing to the size reduction of feed while the contribution of the digestion is less significant. Although rumination efficiency is not appreciably affected by the body size of ruminants, the size of the reticulo-omasal orifice determined by the body size is one of major factors conditioning the size of particles that can pass through the rumen. The contribution of the reticulo-rumen to the digestion of the fibrous fraction amounts to 80% and that of the cecum to 20%, while the contribution of the omasum, abomasum, small intestine, colon and rectum is negligible.

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Discussion

Ku Vera, J. C. (Mexico) : What is the reason for the lower degradability of the NDF fraction in 24 h in the concentrate/alfalfa treatment than in the concentrate/Italian ryegrass diet since the outflow from the rumen was lower in the former than in the latter. Is this phenomenon related to the particle size of the products?

Answer : The exact reason is unknown. However it may be assumed that since the lag time for the NDF of alfalfa hay was longer than that of ryegrass hay and the NDF of alfalfa showed a slower degradation rate in the rumen than that of ryegrass hay, the digestibility of NDF in 24 h in the rumen was lower for alfalfa hay than for ryegrass hay. However, the post-ruminal digestion of NDF of alfalfa has been reported to be higher regardless of the feeding regimens by Taniguchi, Hiroshima University. It is possible to consider that the differences in the content of readily fermentable carbohydrates and lignin between ryegrass and alfalfa may be partly responsible for the difference in the degradation rate of the fibrous fractions between ryegrass and alfalfa.