THE EFFECT OF MECHANICAL PROCESSING OF HAY ON THE EATING AND RUMINATION BEHAVIOUR IN SHEEP

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Summary

An experiment was carried out to investigate the effect of change in length of hay offered on eating and rumination behaviour in sheep using three types of hay diets (L: long, M: 8.0-cm cut, S: 1.2-cm cut) and 3 Japanese Corriedale wethers, and the experiment was designed as 3 × 3 latine square.

The time spent eating per 100 g hay was significantly shorter with long (L) hay ($p < 0.05$) than with chopped (M and S) hay, and therefore, the eating rate (g D.M./min.) was significantly higher in the former ($p < 0.05$) than in the latter. Rumination appearance (the lag time after eating) tended to be longer with long hay than with chopped hay, but not significantly ($p > 0.05$). Daily time spent ruminating, the actual chewing time and daily number of chews tended to be more in feeding long hay than in feeding chopped hay, but not significantly. Daily number of rumination periods was significantly more with long hay ($p < 0.01$) than with chopped hay. Cyclic rate tended to be longer with long hay than with chopped hay, in particular, the difference in values between long hay and 8.0-cm cut hay was significant statistically ($p < 0.01$). The rumination index (time spent ruminating/100 g D. M. eaten) tended to be higher with long hay than with chopped hay, and the difference in values between long hay and 1.2-cm cut hay was significant statistically ($p < 0.05$).

Bolus time was significantly longer with long hay ($p < 0.01$) than that with 8.0-cm cut hay. The circadian pattern of ruminating time was not changed by the changes in length of hay eaten.
(Key Words: Sheep, Hay Length, Eating and Rumination Behaviour)

Introduction

According to Gordon (1958), grinding a dried-grass diet markedly reduced rumination, and this finding could has given a backing to that the higher intake of ground and pelleted forages could be interpreted as having saved the ruminant the trouble of ruminating forage particles to size that will pass from the rumen into the omaso abomasum, because fine particles can pass from the rumen more rapidly than large ones (Campling, 1970). It appears, therefore, in ruminants that one of the important roles of rumination is to decrease the particle size of the diet (Pearce and Moire, 1964; Welch and Smith, 1969). It is fair to assume that rumination behaviour is, at least in part, concerned with changing the physical properties as well as chemical composition of food, in particular roughage feed, so that digestion and utilization are improved. There are some papers showing rumination behaviour is clearly affected by differences in the physical and/or chemical properties of the diet (Campling et al., 1962; Osuji et. al., 1975; Morgan and Campling, 1978; Fujihara, 1981).

On the relationship between the change in length of hay eaten and rumination behaviour, Kick and Gerlaugh (1935) reported that daily time spent ruminating and number of chewing in steers did not change with the changes in length of alfalfa hay (whole, 5-cm and 0.6-cm cut), although that after feeding ground hay was decreased about 1/2 - 2/3 of those with whole or chopped hay. Voskuil and Metz (1973) also reported that when cows were fed ad libitum a whole or chopped (1.4-cm cut) hay, the voluntary intake and daily time spent ruminating did not change with the changes in hay length. These reports, however, have given to us only the relationship between the hay length and ruminating time per day, and as it were, which would be shown as a quantity included in rumination behaviour itself, and then there is no reference

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to the change of quality in rumination behaviour such as mastication and/or chewing efficiency. The paper presented here has shown in detail the results related to the changes in some parameters indicating a quality of rumination behaviour in sheep fed only the grass hay of different length.

Materials and Methods

Animals and diets

Three Japanese Corriedale wethers (nos.501, 503 and 523), each weighing 20-25 kg, were used, and they were kept in metabolism cages throughout the experiment. The sheep were given the 3 diets of hay of different length (1.2-cm cut: S, 8.0-cm cut: M and long: L) in a 3 × 3 latine square design. The sun-cured hay was made from the herbage harvested from a predominantly cocksfoot (*Dactylis glomerata* L.) pasture, and each hay diet was uncut (whole) or cut to 1.2 -(S) and 8.0-cm (M) long before feeding. Chemical composition (as % D.M.) of hay determined by the method of AOAC (Hoitz, 1960), were as follows: organic matter, 92.9; crude protein, 11.2; crude fat, 1.7; crude fibre, 36.0; nitrogen free extract (NFE), 44.0.

Experimental procedure

Six-day sampling periods were preceded by 8-day preliminary periods. Each wether was fed 2.0% of diet per kg body weight per day. Water was freely available, and each sheep had access to a mineralized salt lick at all time. The daily ration was given in equal portions at 09:00 hr and 18:00 hr. During the 6-day sampling period the time spent chewing during eating and ruminating was measured daily by the method of Fujihara (1980) using a wire strain gauge on the lower jaw (Harumoto and Kato, 1979). The term used in this paper for indicating the rumination behaviour is based on the work of Gordon(1955). Statistical analysis of the present study consisted of an analysis of variance and a mean separation using Tukey's multiple range test (Yoshida, 1975).

Results

On the results obtained in this study, the changes of main parameters consisting eating and rumination behaviour were shown in figures, and that of the other parameters were summerized in table 1. When one sheep (no. 501) was fed on unchopped hay (L), the orts (leavings) of ration was more than 10% of the diet, and there was a sparse behaviour during eating, therefore, the value of time spent eating long hay diet (78.5 min/100 g hay eaten) in no. 501 sheep was removed statistically on the average. As shown in figure 1 (b), time spent eating 100 g D.M. of hay was significantly ($p < 0.05$) smaller with long hay diet (41.7 min) than with chopped hay diet (1.2- and 8.0-cm cut), and then the value with 8.0-cm cut hay (60.5 min) tended to be high as compared to that with 1.2-cm cut hay (53.8 min). Rumination appearance (lag time after eating) was tended to be longer with long hay diet than with 1.2- and 8.0-cm cut hays, but not significantly ($p > 0.05$) because there was quite

TABLE 1. EATING AND RUMINATION BEHAVIOUR IN SHEEP FED ON THE DIETS OF HAY CHANGED IN THE LENGTH

Diet	L (whole)	M (8.0 cm)	S (1.2 cm)
Time spent eating (min/day)	157.6 ± 9.1#	220.9 ± 38.0	212.2 ± 33.6
Rate of eating (g D.M./min)	2.4 ± 0.2[a]	1.8 ± 0.2[b]	1.9 ± 0.2[b]
Length of rumination period (min)	21.1 ± 2.8	26.0 ± 2.5	25.7 ± 2.9
No. of boli per rumination period	20.1 ± 3.5	26.6 ± 4.0	25.5 ± 4.0
Daily time spent chewing (min)	427.2 ± 36.0	397.1 ± 81.4	382.3 ± 46.2
	(81.2 ± 5.1)*	(80.8 ± 1.5)	(81.9 ± 2.3)
Daily no. of chewing during rumination	32,712 ± 803	31,290 ± 5,426	29,353 ± 1,592

* Actual chewing time during rumination (% of total rumination time).

\# Mean ± S.D. of 3 sheep.

[a,b] Mean with different superscript in a same line are significantly different ($p < 0.05$).

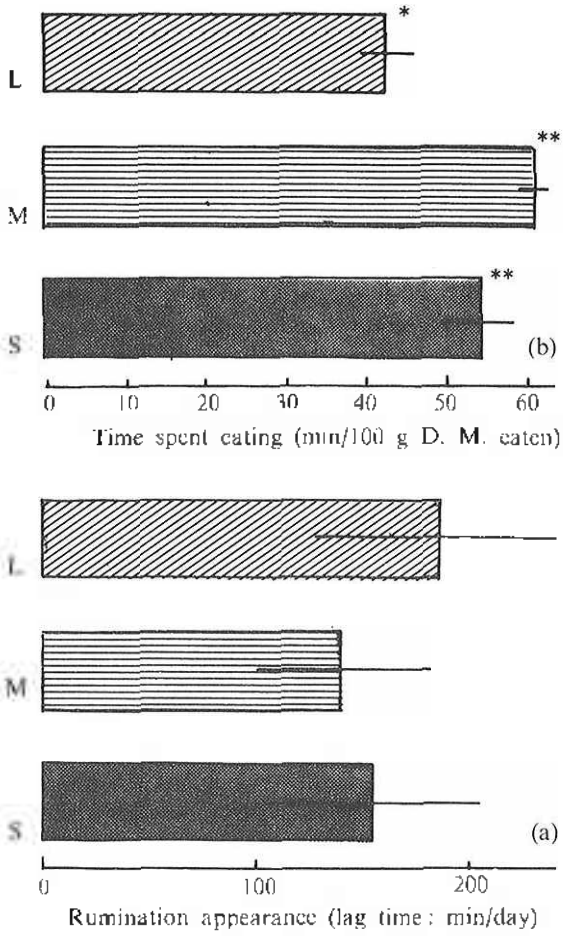

Figure 1. The time spent eating 100 g dry matter and the lag time after eating in sheep fed the diets of hay changed in the length. L: whole hay, M: 8.0-cm cut, S: 1.2-cm cut.
*,**: significant y difference ($p < 0.05$).

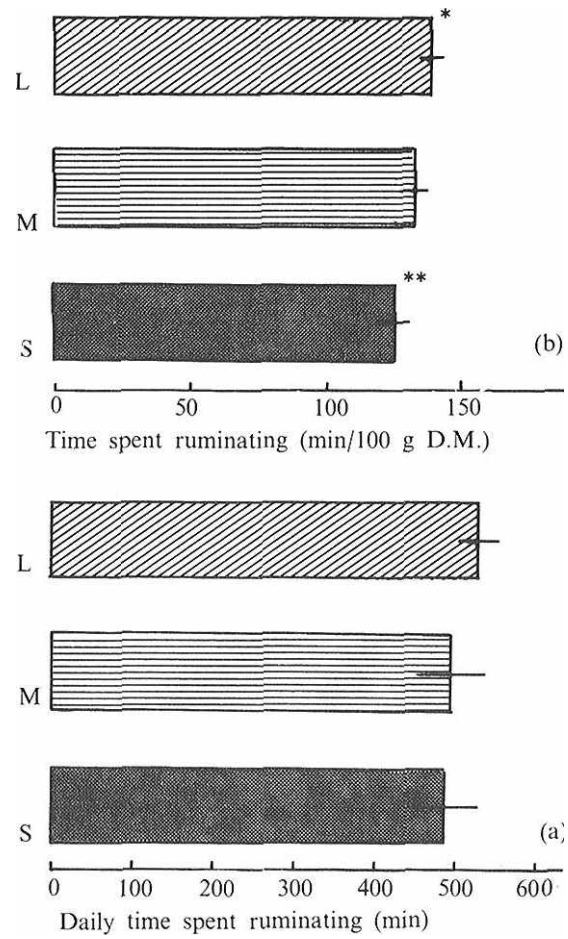

Figure 2. Daily time spent ruminating and time spent ruminating 100 g dry matter in sheep fed the diets of hay changed in the length. L: whole hay, M: 8.0-cm cut, S: 1.2-cm cut.
*,**: significantly difference ($p < 0.05$).

big variations in the values among individual animals (figure 1 (a)).

Daily time spent ruminating was a little bit longer with long hay diet (L) than with chopped hay diets (M and S), but not significantly ($p < 0.05$) (figure 2 (a)). As mentioned above, there was a clear difference in daily hay intake of one sheep (no. 501) with diet L, and then the time spent ruminating per 100g dry matter eaten (rumination index) was significantly higher ($p > 0.05$) with diet L than with diet S, and was also high as compared to that with diet M, but not significantly ($p > 0.05$) (figure 2 (b)).

As shown in figure 3, the daily number of boli regurgitated was almost the same in all the dietary treatments (a). The daily number of rumination periods was significantly more ($p < 0.01$) with diet L than with diets S and M (b). Cyclic rate (total rumination time (sec)/no. of boli regurgitated) tended to be slower with long hay diet than with chopped hay diets, and the figure with long hay diet was significantly higher ($p < 0.01$) than that with diet of 8.0-cm cut hay (c).

The bolus time tended to be long with whole hay diet as compared to those with chopped hay diets, and the value with whole hay was signif-

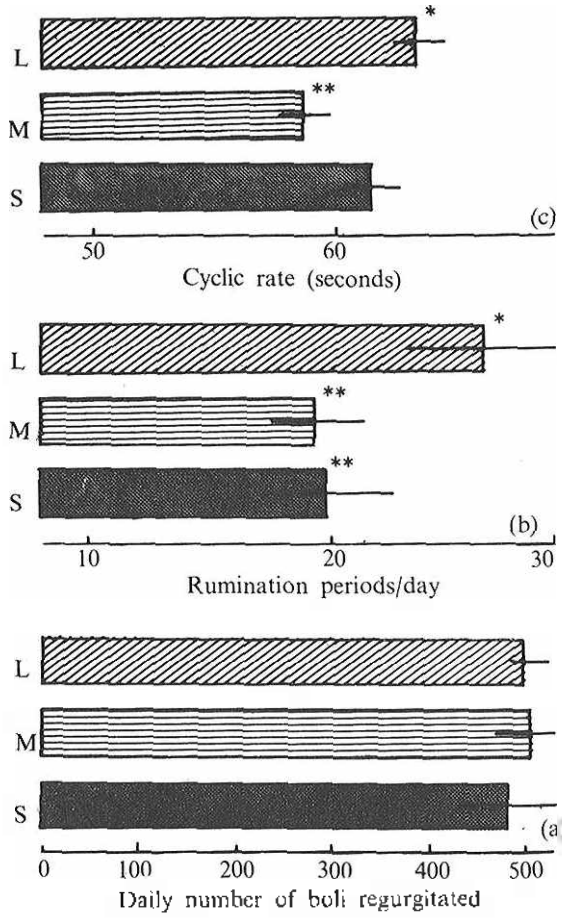

Figure 3. Daily number of boli regurgitated and rumination periods, and cyclic rate in sheep fed the diets of hay changed in the length. L: whole hay, M: 8.0-cm cut, S: 1.2 cm cut.
*,**: significantly difference ($p < 0.05$).

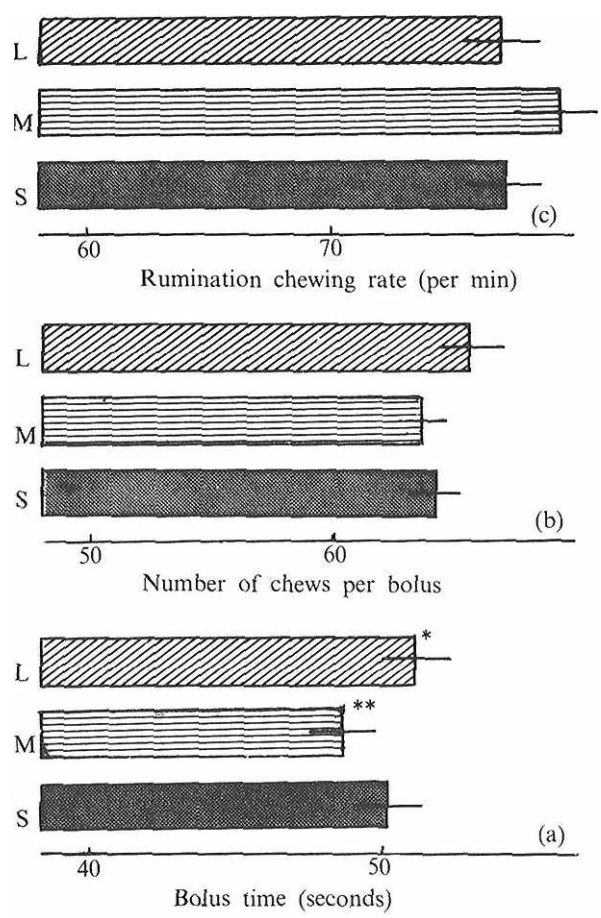

Figure 4. Rumination chewing efficiency in sheep fed the diets of hay changed in the length. L: whole hay, M: 8.0 cm cut, S: 1.2-cm cut.
*,**: significantly difference ($p < 0.05$).

icantly higher ($p < 0.05$) than that with 8.0-cm cut hay diet (figure 4 (a)). The number of chews per bolus also tended to be more with long hay diet than with chopped hay diet, but not significantly ($p > 0.05$) (figure 4 (b)). The chewing rate during rumination was higher with 8.0-cm cut hay than with long and 1.2-cm cut hay, but not significantly ($p > 0.05$) (figure 4 (c)).

Figure 5 shows the circadian pattern of time spent ruminating and the diurnal changes in cyclic rates in sheep received 3 hay diets. The circadian pattern of rumination time did not change in principle with the changes in length of hay offered (a). The diurnal change in cyclic rate with 8.0-cm cut hay was the same as that with long hay in principle, however, that with 1.2 cm cut hay was quite different from those with the other diets (b). The similar phenomenon was observed in the diurnal changes of the average time spent chewing and of the number of chews per bolus (figure 6 (a, b))

Table 1 shows the results of the other parameters consisted eating and ruminating behaviour in sheep fed on the 3 hay diets except that indicated in figures already. Daily time spent eating diet was markedly longer with chopped hay than with whole hay, and then the rate of eating was significantly faster in the former than in the latter. The values in length of rumination periods and the number of boli per rumination period tended

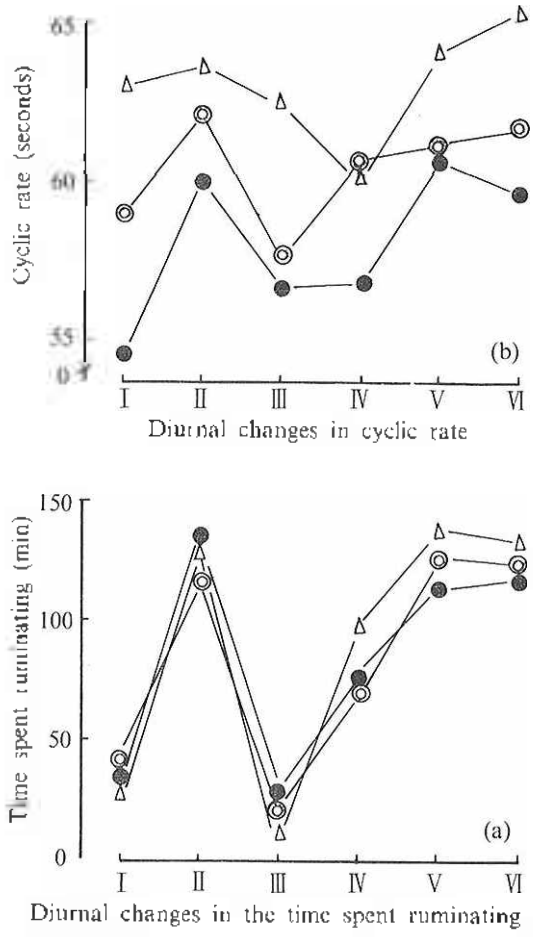

Figure 5. Diurnal changes in the time spent ruminating and in cyclic rate in sheep fed the diets of hay changed in the length. △: whole hay, ⊙: 8.0-cm cut, ●: 1.2 - cm cut.
I: 09:00 13:00 hr, II: 13:00 17:00 hr, III: 17:00-21:00 hr, IV: 21:00-01:00 hr, V: 01:00-05:00 hr, VI: 05:00-09:00 hr.

to be a little bit higher with chopped hay diet than with unchopped long hay diet. Daily actual chewing time during rumination was almost similar in all the dietary treatments, and its percent to total time spent ruminating was also similar (about 80%) in all the diets. Daily number of chewing during rumination tended to be small with chopped hay diet as compared to that with long hay diet, but not significantly because there were relatively big variations in figures among animals.

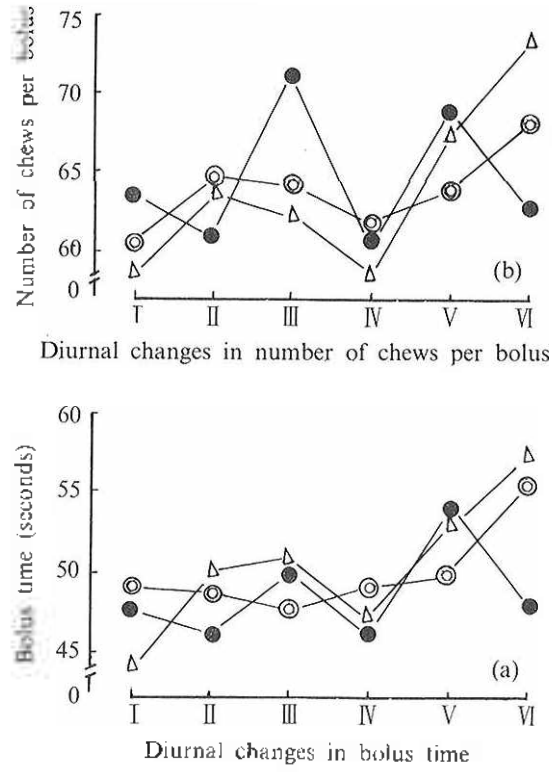

Figure 6. Diurnal changes in bolus time and in number of chews per bolus in sheep fed the diets of hay changed in the length. △: whole hay, ⊙: 8.0-cm cut, ●: 1.2 – cm cut.
I: 09:00 13:00 hr, II: 13:00-17:00 hr, III: 17:00-21:00 hr, IV: 21:00-01:00 hr, V: 01:00-05:00 hr, VI: 05:00 09:00 hr.

Discussion

The results indicated in figure 1 (a) and table 1, clearly indicate that the long hay was more easily formed into a bolus for swallowing than is chopped hay, *i. e.*, the sheep ate long hay diet faster than chopped hay diet. Then the difference in ease of bolus-formation might explain the difference in eating time between the whole and chopped hay. Osuji et al., (1975) reported that, in sheep given the same amount of dry matter in different forms (fresh or dried) of grass, when the rate of eating was high per unit dry matter and *vice versa*. Then, it can be inferred that the energy cost for eating the long hay diet was lower than those for eating the chopped hay diets in

the present experiment. Daily time spent eating long hay diet shown in table 1 was almost the same as those reported earlier using a chopped Italian ryegrass hay (Fujihara, 1980) and a timothy hay (Fujihara and Nakao, 1982).

The rumination was raised slightly faster after eating chopped hay diet than after eating long hay diet in this study, and this clearly indicate that the tactile stimuli of chopped hay after ingestion to a mechano-receptor on the rumen wall was quicker than that after eating whole hay diet as stated earlier (Fujihara and Nakao, 1990). In the previous paper (Fujihara, et al., 1989), it was suggested that the bulk of food ingested, as some physiological load, *i. e.*, a certain stimulus to a mechano-receptor on the rumen wall, could have an obvious effect on rumination appearance (lag time after eating), and then the rumination after eating will be initiated more quickly by some mechanical stimuli than that by a chemical stimulation as a response of chemo-receptor on the rumen wall. In the present experiment, the same hay was used as a sole diet, and daily hay intake by sheep was also similar, and then, a ruminal fermentation of feed was mostly the same in both feedings of chopped and whole hay diets. The difference in the lag time after eating long hay diet and chopped hay diet, therefore, could be clearly due to some differences of tactile stimuli of digesta in the rumen.

It is obvious that the act of chewing during rumination has an important role in the reduction of particle size of feed ingested (Gordon, 1958). As shown in figure 2 (a) and table 1, these findings in this study should indicate the act of chewing to comminute the food particle during eating long hay diet may be rough, and then the ingesta would needed more chewing during rumination as compared to those with chopped hay diet. According to Kick and Gerlaugh (1935), the particle size of ingesta in the rumen of steers was almost the same at 16 hours after eating various lengths hay diets. Balch (1971) also reported that the total time spent by ruminants in chewing their food, during eating and ruminating, should be reasonable to expression of the response of the animal to the physical fibrousness of roughage feed. Then furthermore, he proposed "roughage index" which was indicated as the time spent chewing during eating and ruminating per kg dry matter eaten, and this might show the work done by ruminant in comminuting the food. In the present study, total time spent during eating and ruminating was 684, 716 and 699 minutes per day after feeding the hay diets L (long), M (8.0-cm cut) and S (1.2-cm cut), respectively, and this might indicate that there was, in principle, a prolonged time spent ruminating to compensate a shortened time spent eating the long hay.

Daily number of rumination periods are considered to be a relatively stable parameter composing rumination behaviour in cattle (Hancock, 1953) and sheep (Gordon, 1955; Harumoto and Kato, 1979), though there may be some variations among animals. In the previous report (Fujihara and Nakao, 1990), however, it is clearly suggested that the changes in dietary treatment will be able to lead some changes in daily number of rumination periods of sheep fed roughage feed alone. In this study, daily number of rumination periods was also increased clearly with whole hay diet as compared to those with chopped hay diets, and consequently, time spent ruminating per period was significantly smaller in the former than in the latter. These findings will support in principle the suggestion, in which daily number of rumination periods should be decreased with an decrease in particle size of roughage feed eaten (Fujihara and Nakao, 1990). According to Gordon (1965) and Fujihara et al. (1990), time spent ruminating per rumination period can be clearly changed with a change in daily hay intake by sheep. The result in the present study clearly suggest that the length of hay eaten could influence the time spent chewing per rumination period as well as a change of hay intake in sheep.

As shown in figure 2 (a) and 3 (a, c), as a result, cyclic rate defined by Gordon (1961) with long hay diet tended to be slower than those with chopped hay diets. These facts were relatively in good agreement with that reported by Kick et al. (1937), and clearly suggest that daily number of boli regurgitated would not be influenced by the changes in length of hay eaten. On the other hand, cyclic rate was obviously affected with change of hay length, and this did not support the Gordon's opinion (1965), in which cyclic rate seems to be a relatively unvariable parameter in rumination behaviour of sheep fed

hay alone.

In order to investigate the efficiency of rumination, the number of chews per bolus, bolus time (average time in seconds spent chewing each bolus) and rumination chewing rate were measured (figure 4). With unchopped long hay diet, time spent chewing and the number of chews per bolus tended to be greater than those with chopped hay diet, and this might show that the bolus regurgitated after feeding long hay diet was more hard for chewing and bigger than those after feeding chopped hay diet. Then, the sheep needed a long time and more chewing with long hay diet as compared to those with chopped hay diets. Rumination chewing rate, however, was considered to be a parameter which would not be relatively changed by changing the length of hay eaten. According to Gordon (1965), time spent ruminating per bolus was decreased with a decrease of hay intake by sheep, although there was no changes in cyclic rate. From these findings, it is clear that the ruminating time per bolus could be influenced by changes in length as well as volume of hay eaten. It is obvious that rumination chewing rate is influenced with a change of feed eaten (Harumoto, 1973; Fujihara, 1980). While, it may be presumed that the chewing rate during rumination would be different due to a hereditary individuality of the animal. The ability of mechanical digestion through rumination in sheep, however, may be considered to be similar when their body weight is similar and their feeding condition is also similar, *e. g.*, as in the present experiment. Then, it may be reasonable to consider that the difference in chewing efficiency for comminuting the particle size of food will be mainly due to a difference in daily number of chews during rumination. On the other hand, the efficiency of chewing during rumination (remastication) could be also influenced by some differences in the condition and size of the teeth, and in characteristics of muscle relating the chewing. It may be, therefore, difficult to understand surely an individual chewing efficiency to comminute the particle size of food, and then, it is necessary to reconsider the significance of chewing rate which can be easily measured by observation of the behaviour.

In order to investigate the circadian pattern (daily periodicity) of rumination behaviour, a day (24 hours) was expediently devided into 6 periods (each 4 hours), and the time spent ruminating and cyclic rate were compared with the 3 dietary treatments. The circadian pattern of time spent ruminating (figure 5 (a)) was in agreement with that reported earlier (Harumoto, 1973), and this clearly reconfirmed the daily pattern of rumination in sheep. Pearce (1965) had tried to explain the circadian pattern of rumination by the time course changes of fibrous materials in the rumen after feeding, although he could not has explained the significance of "lag period" as indicated as the lag time after eating in the present study. Then, he has supposed the existence of some factors controlling rumination behaviour except the fibrous materials in the rumen. Gordon and McAllister (1970) had concluded that a mechanism of rumination initiation could be controlled by the light as environmental factors and also a "biological clock" as a periodical 24 hours, and these should make a circadian rhythm in principle. As shown in figure 5 (a), it was clear that the difference in length of hay eaten might not be a main factor affecting original pattern of circadian rhythm for rumination, and the difference in daily time spent ruminating with the 3 dietary treatments was clearly due to a difference in time spent ruminating during the night time.

According to Voskuil and Metz (1973), the daily time spent ruminating and number of boli regurgitated were almost similar when sheep were fed on long hay or chopped (about 1.4-cm cut) hay diet, and there was a positive correlationship between rumination time and number of boli ($r = 0.88$, long hay: $r=0.91$, chopped hay). In the present study, however, there was a relatively certain relationship between daily increase or decrease of ruminating time and cyclic rate. As shown in figure 5 (b), diurnal change of cyclic rate was fairly changed with a change in the length of hay diet, and this clearly indicate that a physical and/or chemical property of bolus regurgitated should be changed along with the time course changes after eating. Then, the characteristic of bolus to be rechewed might be an important exogenous factor controlling rumination behaviour, and this would be obviously reflected in the differences of periodical changes of time spent chewing and the number of chews per bolus along with the change in length of hay eaten (figure 6 (a,b)). From these results, it can be obviously concluded that the change in length

of hay eaten has clearly influenced the quality of rumination behaviour more than quantity of rumination, such as rumination time, as indicated as total time spent ruminating and/or total number of boli.

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