

Factors affecting the voluntary intake of food by cows

6*. A preliminary experiment with ground, pelleted hay

By R. C. CAMPLING, M. FREER† AND C. C. BALCH

National Institute for Research in Dairying, Shinfield, Reading

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The time taken for particles of roughage to be reduced to a size suitable for transfer from the reticulo-rumen to the omasum may be the major factor determining the retention time of roughage residues in the rumen and thereby may partly regulate the voluntary intake of roughage by the cow (Campling, Freer & Balch, 1961, 1962). The size of particles of hay can readily be reduced by grinding. An experiment was conducted, therefore, to examine the effect, on the voluntary intake of hay by cows, of grinding and pelleting the hay, and throughout this report the term 'ground hay' will be used to describe the ground, pelleted hay.

The cost of grinding and pelleting roughages is high, but there has been some practical interest in the convenience with which the product can be handled. In evaluating this method of preparation, the voluntary intake and utilization of the product must be considered. Several studies have been made of the effects of grinding roughage on the digestibility of the roughage, the time of retention of food residues in the alimentary tract, energy metabolism and animal production (e.g. by Blaxter, Graham & Wainman, 1956; Blaxter & Graham, 1956; Meyer, Gaskill, Stoewsand & Weir, 1959; Rodrigue & Allen, 1960). Under certain conditions, grinding roughage appears to exert profound effects on the utilization of diets in which it is included and definition of the critical features in these changes will be an important stage in the understanding of ruminant digestion.

EXPERIMENTAL

The voluntary intakes of long hay and ground hay were compared with four cows (D, E, F and G) in a simple change-over design. Each of the two periods lasted 33 days and included a 3-week preliminary feeding period and 10 days during which voluntary intake, digestibility, and the retention time of stained food particles in the alimentary tract were measured. In a further 2 days the weights of the contents of the reticulo-rumen and the amounts of dry matter they contained were determined.

In a further two periods, comparisons were made between long hay and ground hay with two of the cows (D and E) given equal amounts of food dry matter (8.7 lb/day). The digestibility of each food was measured, together with the mean time of retention of food residues in the gut and the rate of breakdown of cotton thread in the rumen.

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† Present address: C.S.I.R.O., Division of Plant Industry, Canberra, Australia.

Cows and housing. Four adult, non-lactating, non-pregnant cows were used; three of the cows (E, F and G) were Shorthorns and one (D) was a Friesian. The mean live weight of the cows during the experiment was about 1150 lb. Each cow had a permanent rumen fistula. The cows were kept in standings which prevented food being stolen by neighbours. Water and salt licks containing trace minerals were accessible at all times.

Food. A batch of ryegrass hay was divided into two parts; one part was ground commercially in a large hammer-mill with a screen with apertures of 0.049 in. diameter and then pelleted with the addition of steam only (Nottingham Crop Dryers Ltd). The chemical composition of samples of long hay and ground hay are shown in Table 1. There were differences between the crude protein and dry-matter contents of the long hay and ground hay; no other differences were apparent. The size of the particles was measured by shaking for 5 min a sample of ground hay through a series of test sieves (British Standard Specification 410, 1943) on a mechanical sieve shaker. The size of the apertures of each sieve and the amount of hay retained on each sieve are given in Table 2. Each cow received daily 40 g of a proprietary mineral mixture (Churn, 105; British Glues & Chemicals Ltd) together with a weekly supplement of a concentrate of vitamins A and D (Drivite; Boots Pure Drug Company Ltd).

Table 1. *Chemical composition of the foods*

Diet	Dry matter (%)	Organic matter	Crude protein	Ether extract	Crude fibre	Nitrogen-free extract	Ash
Long hay	85.2	92.8	7.8	1.5	31.5	51.9	7.2
Ground hay	91.1	92.4	6.8	1.6	30.6	53.4	7.6

Table 2. *Distribution of particle size of ground hay as determined by sieving through British Standard test sieves*

Sieve mesh no.	Aperture (μm)	Percentage of hay retained on sieve
16	1003	0.2
22	699	1.1
30	500	3.1
44	353	15.0
60	251	23.0
85	178	20.1
100	152	6.3
120	124	7.2
150	104	8.8
Residue	—	15.2

Determination of voluntary intake of hay. The daily allowance of long hay or ground hay was offered in one meal for 5 h and the uneaten food was then removed and weighed. The amount offered was adjusted daily so that the uneaten food was about 10% of the amount offered.

Digestibility. The digestibility of the long hay and of ground hay was determined in

the usual way with the harness and equipment described by Balch, Bartlett & Johnson (1951).

Digestibility in the reticulo-rumen. The extent of digestion of long hay and of ground hay in the reticulo-rumen was estimated by the lignin-ratio technique (Balch, 1957; Campling *et al.* 1961).

Rate of breakdown of cotton thread in the reticulo-rumen. The cotton-thread technique described by Campling *et al.* (1961) was used to obtain an index of the rate of digestion of cellulose in the reticulo-rumen.

Mean time of retention of undigested residues. The time of retention of food residues in the alimentary tract was measured after giving by mouth about 4% of the daily food intake stained with magenta and counting the number of stained particles in subsequent samples of faeces (Balch, 1950). The mean time of retention of stained particles in the gut was expressed in the way suggested by Castle (1956).

Amount of digesta in the reticulo-rumen. The total weight of digesta and the amount of digesta dry matter were determined, by removing and returning the digesta through the fistula, before and after feeding on 2 days at the end of each treatment period.

RESULTS

Voluntary intake of hay. The mean daily voluntary intake of long hay and of ground hay by each cow is shown in Table 3. Mean values for all the cows were 20.4 lb dry matter as long hay and 20.8 lb dry matter as ground hay. Two cows (E and G) showed appreciable differences from the mean; cow E ate 18.7 lb dry matter as long hay and 22.5 lb dry matter when offered ground hay, whereas cow G ate 1.7 lb more dry matter in the form of long hay than as ground hay.

Table 3. Mean daily voluntary intake of hay dry matter by each cow (lb)

Diet	Cow D	Cow E	Cow F	Cow G	Mean
Long hay	21.8	18.7	20.0	21.0	20.4
Ground hay	21.6	22.5	20.0	19.3	20.8

Digestibility. The mean values for the apparent digestibility of each food offered *ad lib.* are shown in Table 4; values for individual cows have also been given because of the variation between cows, particularly in the digestion of the crude fibre of the ground hay. The results show that the ground hay was markedly less digested than the long hay; the mean digestibility of the organic matter of the ground hay was only 42.9% compared with 63.6% for the long hay. The difference in the digestibility of the organic matter was due to the low digestibility of the crude fibre and nitrogen-free extract fractions of the ground hay. In general, the crude fibre of the ground hay was digested only half as well as that of the long hay. No significant differences were found between the digestibilities of the crude protein and ash fractions of the long and ground hay. Differences between the cows in the extent to which food was digested were most marked with cows D and F. The digestibility was lowest in cow D which digested 61.8% of the crude fibre of the long hay and only 26.0% of the fibre of the ground hay. Cow F digested both foods to a greater extent than did the other cows.

Thus it digested 68.3% of the crude fibre of the long hay and 37.4% of the fibre of the ground hay.

When both foods were given in restricted but equal quantities the mean digestibility of the dry matter of the ground hay eaten by cows D and E was 46.0% compared with 42.8% when they ate as much as they wished (see Table 4). The corresponding means for long hay were 59.0 and 61.8% respectively. A marked depression was again found in the digestibility of the crude fibre of the ground hay.

Digestion in the reticulo-rumen. Results obtained with the lignin-ratio technique are given in Table 5. The organic matter, crude fibre and nitrogen-free extract of the ground hay given *ad lib.* were digested in the reticulo-rumen to a much lesser extent than with the long hay given *ad lib.* It was apparent that differences between cows in the digestibility of food were due to differences in the extent of digestion in the reticulo-rumen; in general cow D showed the lowest values and cow F the highest values.

Table 4. *Apparent digestibility (%) of long hay and ground hay by four cows*

Cow	Mean daily intake of food dry matter (lb)	Digestibility (%)						
		Dry matter	Organic matter	Crude protein	Ether extract	Crude fibre	Nitrogen-free extract	Ash
<i>Ad lib. feeding</i>								
D	21.8 long hay	57.5	59.6	35.9	38.6	61.8	62.2	31.5
	21.6 ground hay	39.6	39.6	26.3	54.9	26.0	46.4	40.0
E	18.7 long hay	62.3	64.0	35.1	46.4	67.6	65.6	41.8
	22.5 ground hay	41.4	41.6	23.6	49.5	33.6	47.2	39.3
F	20.0 long hay	64.1	65.3	25.6	45.1	68.3	67.0	49.3
	20.0 ground hay	47.3	47.6	40.5	57.5	37.4	52.0	44.1
G	21.0 long hay	63.5	65.3	26.0	48.2	66.9	67.8	41.7
	19.3 ground hay	43.0	42.8	27.2	54.0	29.5	50.4	44.6
Mean	20.4 long hay	61.8	63.6	30.6	44.6	66.2	65.6	41.1
	20.8 ground hay	42.8	42.9	29.4	54.0	31.6	49.0	42.0
<i>Restricted feeding</i>								
D	8.7 long hay	59.4	62.3	39.9	43.3	65.3	63.4	39.0
	8.7 ground hay	45.0	47.0	26.4	45.1	39.3	53.8	15.4
E	8.7 long hay	58.6	61.3	33.1	29.8	65.9	63.3	35.6
	8.7 ground hay	47.1	48.4	32.5	46.5	38.4	55.9	30.0
Mean	8.7 long hay	59.0	61.8	36.5	36.6	65.6	63.4	37.3
	8.7 ground hay	46.0	47.7	29.4	45.8	38.8	54.8	22.7

At the restricted level of food intake, the organic matter, crude fibre and nitrogen-free extract of the ground hay were digested to a much lesser extent than those of the long hay by cow D, but in cow E the digestion of only the crude fibre of the ground hay was depressed; no significant differences were found in the digestibility of the organic matter and nitrogen-free extract.

Rate of breakdown of cotton threads. The times taken for coils of cotton thread placed in the rumen to lose 25% of their weight are given in Table 6. The mean time in cows given long hay *ad lib.* was 32 h and with ground hay it was 282 h, an observation which

confirms that of Balch & Johnson (1950). Some variation between individual cows was found; the rate of loss was slowest in cow G given ground hay. At the restricted level of food intake the mean time for 25% loss of cotton thread in cows D and E with long hay and with ground hay was 20 h and 82 h respectively.

Table 5. *Apparent digestibility (%) of long hay and ground hay in the reticulo-rumen of four cows*

Cow	Diet	Organic matter	Crude fibre	Nitrogen-free extract
<i>Ad lib. feeding</i>				
D	Long hay	46.4	43.2	59.5
	Ground hay	22.9	7.5	34.6
E	Long hay	42.8	52.8	46.1
	Ground hay	27.4	15.2	39.0
F	Long hay	55.2	57.8	64.2
	Ground hay	22.8	13.0	36.6
G	Long hay	46.3	47.9	59.8
	Ground hay	27.6	15.9	37.8
Mean	Long hay	47.7	50.4	57.4
	Ground hay	25.2	12.9	37.0
<i>Restricted feeding</i>				
D	Long hay	37.0	48.1	43.3
	Ground hay	14.3	9.6	26.1
E	Long hay	36.4	46.5	40.7
	Ground hay	34.7	33.1	41.7
Mean	Long hay	36.7	47.3	42.0
	Ground hay	24.5	21.4	33.9

Table 6. *Time (h) for 25% loss of weight of cotton thread in the ventral sac of the reticulo-rumen of four cows*

Diet	Cow D	Cow E	Cow F	Cow G	Mean
<i>Ad lib. feeding</i>					
Long hay	27	26	41	33	32
Ground hay	182	230	225	490	282
<i>Restricted feeding</i>					
Long hay	21	19	—	—	20
Ground hay	90	75	—	—	82

Mean time of retention of undigested residues. In three cows (E, F and G) there was relatively little difference between the mean retention times of the residues from each food given *ad lib.* (Table 7); however, in cow D the ground-hay residues had a much shorter time of retention in the alimentary tract than residues from the long hay. The initial excretion of hay particles was faster with ground than with long hay and in two of the four cows the final excretion was distinctly more prolonged. This is illustrated in Fig. 1 which shows the mean cumulative excretion curves of the stained foods. Balch (1950) reported similar changes in excretion when hay was ground.

When the daily food intake of cows D and E was restricted to 8.7 lb dry matter the mean retention time of long hay was greater than when this food was offered *ad lib.*;

this was in agreement with the previously reported effects of level of intake on retention time (Balch, 1950; Campling *et al.* 1961). With the restricted level of ground hay, the mean retention time was longer than that observed with the unrestricted level in cow D, but in cow E the retention time was 60 h, about the same as that found when ground hay was offered *ad lib.*

Table 7. *Times of retention (h) of stained hay in the alimentary tract of four cows*

Diet	Cow D	Cow E	Cow F	Cow G	Mean
<i>Ad lib.</i> feeding					
Long hay	58	64	71	68	65
Ground hay	41	63	73	75	63
Restricted feeding					
Long hay	73	97	—	—	85
Ground hay	52	60	—	—	56

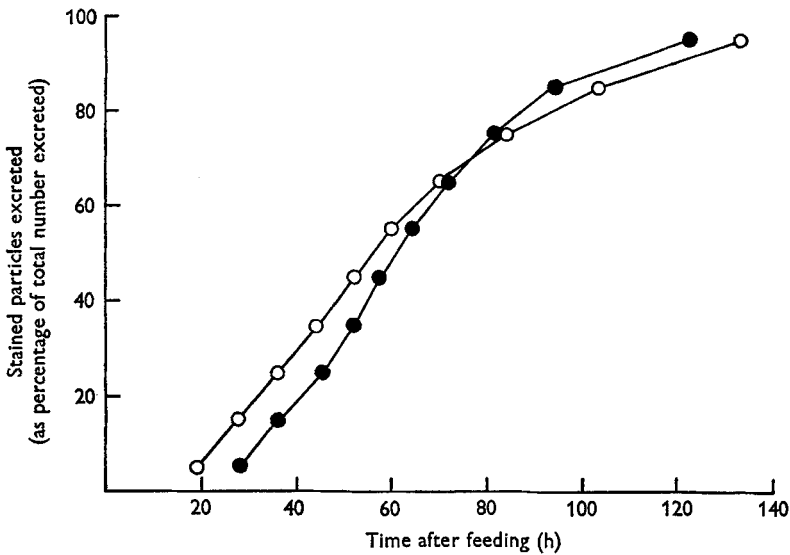


Fig. 1. Mean values for the excretion of undigested hay residues at intervals after eating stained hay. Values are for four cows receiving diets of long hay (●—●) and ground hay (○—○). Excretion is shown as the percentage of the total stained particles excreted.

Amount of digesta in the reticulo-rumen. Immediately before a meal there were slightly more digesta and digesta dry matter in the reticulo-rumen of the cows when offered long hay than when they were offered ground hay but this difference was not consistent. Only in cow D was the difference large (Table 8). Mean values for the amount of digesta found in the reticulo-rumen before a meal were 193.7 lb (19.6 lb dry matter) with long hay and 160.1 lb (18.2 lb dry matter) with ground hay. At the end of a meal slightly more digesta and digesta dry matter were found in the reticulo-rumens of three cows (D, F and G) when long hay was offered than when ground hay was given; the opposite was found for the fourth cow (E). Mean values for the amount

of digesta and of dry matter after a meal of long hay and a meal of ground hay differed by 24 and 9% respectively.

The rate of loss of digesta during a meal was 1.75 lb dry matter/h with ground hay and only 0.84 lb dry matter/h with long hay. The mean rates of loss between meals were much less dissimilar, 0.70 lb dry matter/h with ground hay and 0.82 lb dry matter/h with long hay.

Table 8. Amount of digesta (lb) in the reticulo-rumen of four cows before and after receiving hay *ad lib.*

Diet	Cow D		Cow E		Cow F		Cow G		Mean	
	Total	Dry matter	Total	Dry matter	Total	Dry matter	Total	Dry matter	Total	Dry matter
	Before feeding									
Long hay	150.2	14.42	232.7	21.27	185.7	20.00	206.1	22.86	193.7	19.64
Ground hay	105.6	9.76	175.4	20.66	183.0	22.78	176.4	19.76	160.1	18.24
	After feeding									
Long hay	229.0	30.16	301.4	35.11	262.0	36.30	271.8	36.96	266.0	34.63
Ground hay	162.4	21.10	245.2	38.30	212.7	33.68	239.4	33.28	214.9	31.60

It was noticeable that the digesta found in the reticulo-rumen of cows given ground hay were a homogeneous mass, well described by Blaxter & Graham (1956) as a thick purée without the typical stratification into solid and liquid portions found when long roughages are given. This difference in physical form of the digesta in the reticulo-rumen was not associated with a large difference in the total content of water. The mean dry-matter content of the digesta (calculated from Table 8) before feeding was 10.1% with long hay and 11.4% with ground hay; after feeding the means were 13.0 and 14.7% respectively. However, at the reticulo-omasal orifice, large differences were found between the dry-matter contents of the digesta derived from ground and long hay; the ground-hay digesta from this region contained 11.8% dry matter and long-hay digesta only 4.1% dry matter.

DISCUSSION

There was no difference between the mean daily voluntary intake of dry matter by the cows in the form of long and ground hay, but in all four cows the digestibility of ground hay was much lower than that of long hay. Several workers have observed greater food consumption in sheep when roughages were given in a ground, pelleted form than when given long (Meyer *et al.* 1959; Lloyd, Crampton, Donefer & Beacom, 1960; Van der Merwe, Ferreira, Vosloo & Labuschagne, 1962), but there are few reports comparing ground and long hay offered *ad lib.* as the only food to cattle. When the hay was ground, Wallace & Hubbert (1959) found an increase of 31% in the intake of food by small steers of 365 lb live weight but observed no differences in the digestibility of the dry matter between long and ground hay. Webb, Cmarik & Cate (1957) and Beaty, McCreery & Brooks (1960) also found an increased intake of hay as a result of grinding and pelleting but reported no digestibility coefficients. Some of the earlier reports on the effect of grinding hay were reviewed by Balch & Campling (1962) and

a more comprehensive review of the subject has been published recently by Minson (1962).

The depression in digestibility of the ground hay found in this experiment agrees with many reports of work with cattle (Balch, 1950; Rodrigue & Allen, 1960) and sheep (Blaxter & Graham, 1956; Lloyd *et al.* 1960); a few reports show no significant differences in digestibility between ground and long hay (Meyer *et al.* 1959; Wallace & Hubbert, 1959). Also, Rodrigue & Allen (1960) found that the fineness of the ground hay affected its digestibility; the finer the hay was ground the greater was the depression in digestibility. Our results may be compared most closely with those of Rodrigue & Allen (1960), who in one comparison used very finely ground hay similar in size of particles to the ground hay used by us, but unfortunately no other reports give the distribution of size of the particles of ground hay. In general, our results agree with those of Rodrigue & Allen except that the depression in digestibility of the dry matter and nitrogen-free extract of the ground hay was greater than that found by those authors. This difference may have arisen because Rodrigue & Allen gave an allowance of concentrates in addition to roughage to their cows. As has been found by other workers (Blaxter & Graham, 1956; Rodrigue & Allen, 1960), the depression in digestibility caused by grinding was most marked in the crude-fibre fraction. Blaxter & Graham suggested that a possible cause for the poor digestibility of ground hay may be the more rapid passage of ground hay than of long hay through the reticulo-rumen.

Blaxter *et al.* (1956), using sheep, and Rodrigue & Allen (1960), using cattle, found a faster rate of passage of ground-hay than of long-hay particles through the alimentary tract. Blaxter *et al.* (1956) and Meyer *et al.* (1959) suggested that a shorter mean time of retention of ground hay in the gut would be partly responsible for an increased intake of ground roughage relative to long roughage.

When ruminants have been given ground hay in place of long hay, the observed effects on digestibility, mean retention time and voluntary intake have clearly been variable. In the experiment reported now the *ad lib.* intakes of long hay and of ground hay were similar, but the mean digestibility of the dry matter of the ground hay was 19 percentage units lower than that of the long hay. Since the mean retention times of long and ground hay in the gut were also similar, the gut must on average have contained more dry matter with ground hay than with long hay. There was, however, no consistent increase in the weight of dry matter found in the reticulo-rumen with long and with ground hay. It follows, therefore, that with unrestricted intakes the hind gut contained appreciably more dry matter with ground hay than with long hay. Also, it is suspected that the mean retention time of ground hay in the reticulo-rumen was shorter than that of long hay.

It is likely that the rate of breakdown of digesta in the reticulo-rumen was slow with ground hay, as indicated by the slow rate of breakdown of cotton threads suspended in the ventral sac of the rumen. The high dry-matter content of digesta in the ventral sac of the rumen and possibly a shorter time of retention of ground hay than of long hay in the reticulo-rumen, together with a more rapid release and absorption of the soluble constituents of the ground hay, may have contributed to the relatively unfavourable conditions for cellulose digestion. Also, the lower content of crude protein

in the ground hay than in the long hay may have contributed to the lower digestibility of the ground hay.

Although the mean retention times for stained hay in the whole gut were not markedly altered by grinding the hay, the shapes of the excretion curves were different with the two diets in three of the four cows. Clearly the need for rumination must tend to delay the initial passage of all but the smallest particles of stained long hay from the reticulo-rumen. However, individual particles from the stained meal of long hay would have a progressively greater chance of leaving the reticulo-rumen than particles from subsequent meals. With a diet of ground hay the individual particles of a stained meal would be expected to have about the same chance of leaving the reticulo-rumen as particles from previous and subsequent meals. The cumulative excretion curve for stained ground hay given *ad lib.* would therefore be expected to show a pattern of relatively more rapid initial excretion and more prolonged subsequent excretion than would the curve for stained long hay, given *ad lib.*, as was observed in these three cows (Fig. 1) and in three out of four cows studied by Balch (1950). The experiment reported now illustrates the difficulty of deducing the amount of digesta in a section of the gut from a study of excretion curves alone. The amount of dry matter found in the reticulo-rumen immediately before and after eating was slightly, but not consistently, less with ground hay than with long hay. The results for cows E-G were in agreement with our earlier hypothesis that with one meal daily the voluntary intake is regulated in relation to the amount of digesta in the reticulo-rumen. With long hay, the rate of breakdown of food particles probably limited the rate of disappearance of digesta from the reticulo-rumen, but with ground hay it is possible that this limitation was imposed by the rate of elimination of digesta from the hind gut.

In cows receiving ground hay *ad lib.*, the amount of dry matter in the hind gut may have exerted an indirect effect on the voluntary intake by limiting the rate of disappearance of digesta from the reticulo-rumen. However, it could also happen, especially in an animal behaving as cow D, that distension of the hind gut might directly regulate the voluntary intake of ground hay.

There is no reason to suppose that under the conditions of a particular experiment the several effects of grinding hay will always be quantitatively equal. Thus there may well be conditions in which the species of animal, the level of feeding, the type of roughage, the degree of grinding or the presence of other foods will cause a change in the rate of digestion different from that caused in the rates of passage and of flow of the ground material from the reticulo-rumen. These differences, especially in combination with the possible effects of changes in the amount of digesta in the hind gut, could explain why some workers have found the fall in digestibility on grinding to be associated with a longer retention time and some with a shorter. Such differences would also explain why grinding has sometimes been found to increase the voluntary intake of roughages whereas in other experiments it has caused no increase.

The hypothesis put forward above could also provide an explanation for some of the other conflicting results found in previous comparisons of ground and long hay. When food intake is restricted, the lower amount of 'fill' in the hind gut would not be

expected to limit flow from the reticulo-rumen, and thus the mean retention time of ground hay would be shorter than that of long hay, as observed in this experiment.

SUMMARY

1. The effect of grinding hay on the voluntary intake of food by cows was examined in a change-over design with four non-pregnant, non-lactating cows. The long hay and the ground hay were prepared from similar herbage; the ground hay was offered in the form of pellets. The distribution of the size of particles of ground hay is given.

2. The mean daily voluntary intakes of hay dry matter by the cows were similar with long hay and ground hay, but the digestibility of the ground hay was much lower than that of the long hay. The low digestibility of the ground hay was due to the poor digestion of crude fibre and of nitrogen-free extract in the reticulo-rumen.

3. The rate of disappearance of cotton threads suspended in the ventral sac of the rumen was about nine times slower with ground hay than with long hay.

4. With unrestricted intakes, the mean retention times of stained food residues were similar with the long and the ground hay, although the initial excretion of the ground hay was faster than that of the long hay and in three cows out of four the final excretion was more prolonged. At the restricted level of food intake ground hay was retained in the gut for a considerably shorter time than long hay.

5. The results are discussed in relation to the varying effects that have been observed in experiments in which ruminants received ground roughage. It is suggested that with a given diet the influence of grinding on the voluntary intake and digestibility of the diet will depend on the extent to which both the retention time and rate of breakdown of digesta in the gut are altered by the grinding.

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