Factors affecting the voluntary intake of food by cows

8.* Experiments with ground, pelleted roughages

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1. Two experiments were conducted to examine the effect of grinding and pelleting roughages on the voluntary intake of food, digestibility, time of retention of food in the digestive tract, amounts of digesta in the recitulo-rumen and eating and ruminating behaviour of adult, non-lactating, non-pregnant cows. The first experiment was with artificially dried grass and the second with oat straw; also, with a diet of ground, pelleted oat straw the effect was studied of giving a daily intraruminal infusion of 150 g urea. The size of the particles of the ground roughages are given. 2. The mean voluntary intakes of long and ground dried grass were similar, the voluntary intake of ground, pelleted oat straw was 26% greater than that of long straw and the daily infusion of urea increased the voluntary intake of ground, pelleted oat straw by 53%. 3. The digestibility of the ground roughages was lower than that of the long roughages, the lower digestibility of the ground roughages was due mainly to the poor digestibility of crude fibre in the reticulo-rumen. The rate of disappearance of cotton thread placed in the ventral sac of the rumen was slower with ground than with long roughages. 4. The mean times of retention of ground roughages were shorter than those of long roughages when equal and restricted amounts of each food were given; with food offered *ad lib.* there was little difference between the mean times of retention of long and ground roughages in the alimentary tract. 5. On average, the mean amounts of digesta dry matter in the reticulo-rumen immediately after a meal were about the same with long and ground dried grass, with long and ground oat straw the amounts of dry matter were similar, but when the intraruminal infusion of urea was given the amount of dry matter increased by 49%. 6. The rate of eating (min/kg food) ground, pelleted roughages was much faster than that with long roughages; when the cows received ground roughage rumination did not occur but during short periods triple reticular contractions were seen. 7. The relationship between the voluntary intake of food, the amount of digesta in the reticulo-rumen and the rate of disappearance of digesta from the alimentary tract is discussed.

Grinding reduces the size of particles of roughage and this might be expected to increase the rate of passage of undigested residues through the alimentary tract of the cow and thereby increase the voluntary intake of food (see Balch & Campling, 1962; Campling, Freer & Balch, 1963). Although in a preliminary experiment we found no increase in voluntary intake of food associated with grinding and pelleting hay, we suggested that the effect of grinding roughages upon voluntary food intake would depend on the type of roughage, fineness of grinding and species of animal. To conclude this investigation of factors affecting the voluntary intake of food by cows, the present experiments investigated the effects of grinding different roughages on the voluntary intake of food by cows, digestibility, the rate of passage of undigested food residues through the gut, the amount of digesta in the reticulo-rumen and the eating and ruminating behaviour of the cows.

Two experiments were conducted, the first with a roughage of high digestibility,

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artificially dried grass, and the second with oat straw, a roughage of low digestibility. Each food was given at two levels of feeding: (1) restricted to about 4·5 kg daily, and (2) *ad lib.* Also, in the second experiment the effect was studied of supplementing a diet of ground, pelleted oat straw with a daily intraruminal infusion of a solution of urea. It was shown earlier that intraruminal infusions of urea increased the voluntary intake of long oat straw by cows by 39 % (Campling, Freer & Balch, 1962). Throughout the report the term ground roughage will be used to describe the ground, pelleted roughages.

EXPERIMENTAL

Plan of experiments

Expt 1. The effect on voluntary intake of food of grinding and pelleting dried grass was studied with four cows (A, B, C and D) in a 4×4 Latin square experimental design with four periods, each of 33 days duration. The four treatments were: (1) 4·5 kg long dried grass daily, (2) 4·5 kg ground dried grass daily, (3) long dried grass *ad lib.*, and (4) ground dried grass *ad lib.* Each period consisted of an 18-day preliminary feeding period, 3 days during which recordings were made of eating and ruminating behaviour, a 10-day collection period when food intake, digestibility, the rate of breakdown of cotton thread in the rumen and the time of retention of stained food in the alimentary tract were measured. The weights of the contents of the reticulo-rumen and the amounts of dry matter they contained were determined before and after feeding on 2 further days.

Expt 2. The effect on voluntary food intake of grinding and pelleting oat straw with and without intraruminal infusions of urea was studied with three cows (E, F and G) in a 3×3 Latin square experimental design with three periods of 44 days. The three treatments were: (1) long oat straw, (2) ground oat straw, and (3) ground oat straw with a daily intraruminal infusion of 150 g urea dissolved in 9 kg water. The method of infusion of the solution of urea was that described by Campling *et al.* (1962). Each treatment period was divided into two parts. The first with food restricted to 3·9 kg dry matter daily consisted of an 11-day preliminary feeding period, 3 days during which recordings were made of eating and ruminating behaviour, a 10-day collection period when digestibility, the rate of breakdown of cotton thread in the rumen and the time of retention of stained food residues in the alimentary tract were measured. In the second part when food was offered *ad lib.*, there was a 6-day preliminary feeding period and a 10-day collection period during which measurements were made of voluntary food intake, digestibility, rate of breakdown of cotton thread in the rumen, and the time of retention of food residues in the alimentary tract. During a further 3 days recordings were made of eating and ruminating behaviour, and finally on each of 2 days the contents of the reticulo-rumen were measured.

Cows and housing. Five adult, non-lactating, non-pregnant cows were used, three Friesians and two Shorthorns. Each cow had a permanent rumen fistula. The mean live weight of the animals was about 544 kg in Expt 1 and 520 kg in Expt 2. The cows were in standings which prevented food being stolen by neighbours. Salt licks, containing trace minerals, and water were always accessible.

Foods. For use in Expt 1, a batch of artificially dried grass was divided into two parts; one part was ground commercially in a large hammer-mill and pelleted with the addition of steam only (Nottingham Crop Dryers Ltd). A batch of oat straw was treated similarly for use in Expt 2. The pellets of ground roughage were about 13 mm in diameter and 20–30 mm long. The chemical compositions of the foods are shown in Table 1. There were slight differences between the long and ground forms of the same roughage in content of dry matter, crude protein, crude fibre, nitrogen-free extract and ash. The size of the particles of ground roughage was measured by shaking for 5 min a sample of ground roughage 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 ground roughage retained on each sieve are given in Table 2. The ground dried grass tended to have a slightly higher proportion of smaller particles than the ground oat straw.

Table 1. *Chemical composition of the foods*

Expt no.	Food	Dry matter (%)	Organic matter	Crude protein	Ether extract	Crude fibre	Nitrogen-free extract	Ash
			(as % of dry matter)					
1 (four cows)	Long dried grass	87·0	87·1	21·8	1·6	21·4	42·3	12·9
	Ground dried grass	88·0	84·6	19·7	1·9	20·0	42·9	15·4
2 (three cows)	Long oat straw	85·7	91·7	3·5	1·7	44·7	41·8	8·3
	Ground oat straw	88·8	91·4	4·2	2·0	38·4	46·8	8·6

Table 2. *Distribution of particle size of the ground roughages as determined by sieving for 5 min through British Standard test sieves*

Sieve mesh no.	Aperture (μm)	Percentage of roughage retained on sieve	
		Dried grass	Oat straw
16	1003	—	0·2
22	699	5·8	6·2
30	500	10·2	9·8
44	353	15·3	25·6
60	251	16·1	23·5
85	178	17·4	14·8
100	152	14·7	3·8
120	124	8·4	4·8
150	104	4·5	4·6
Residue	—	7·6	6·7

During Expt 2 only, each cow received daily 40 g of a proprietary mineral mixture (Churn 105; British Glues and Chemicals Ltd) together with a weekly supplement of a concentrate of vitamins A and D (Drivite; Boots Pure Drug Company Ltd).

Determination of voluntary intake of food. The daily allowance of food 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 foods 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 each food in the reticulo-rumen was estimated by the lignin-ratio technique (Balch, 1957; Campling, Freer & Balch, 1961). In Expt 2 cow F was the only cow in which the extent of digestion in the reticulo-rumen was determined when given food *ad lib.*

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 by 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 period. Digesta were dried at 100° in a forced draught oven.

Eating and ruminating behaviour. The apparatus used to record the eating and ruminating behaviour of the cows was that described by Freer, Campling & Balch (1962) and Balch, Kelly & Heim (1951) and consisted of a small, lightly inflated balloon retained by a brass weight in the reticulum. The balloon was connected to a tambour in an Evershed and Vignoles recorder. A similar balloon was placed under a side strap on a leather head-stall to record jaw movements. Each tambour operated a pen and provided a continuous record of the frequency of pressure changes at 0·5 in/min. Records of reticular motility and jaw movements were made simultaneously with each diet, being started immediately before a meal and continuing for 72 h. The records were analysed to determine the time the cows spent eating, ruminating, resting, standing and lying; resting was a residual activity during which the cows were neither eating nor ruminating. The frequency of the contractions of the reticulum during each activity was calculated, and for this purpose each double or triple contraction of the reticulum was counted as one contraction.

RESULTS

Voluntary intake of food

Expt 1. The mean daily voluntary intakes of food were about the same with long and ground dried grass, 10·9 kg long dried grass and 10·7 kg ground dried grass (Table 3). Although two of the cows (A and D) ate similar amounts of dried grass in the long and ground forms, cow B ate 2·7 kg or 27% more long than ground dried grass and cow C ate 1·5 kg or 17% more ground than long dried grass. The mean amounts of water drunk by the cows given long and ground dried grass were similar (Table 3).

Expt 2. The mean daily intake of long oat straw was 5·7 kg, of ground oat straw

7·2 kg and of ground oat straw with urea 11·0 kg (Table 3). Thus grinding was associated with an increase in food intake of 1·5 kg or 26%, and the effect of the infusion of urea was to increase the intake of ground straw by 3·8 kg or 53%. Grinding together with the infusion of urea increased the intake of straw by 5·3 kg or 93% over the voluntary intake of long straw. The mean voluntary intake of long straw was 6·1 kg by cow E, 5·7 kg by cow G and 5·2 kg by cow F; grinding was associated with an increase in intake of straw of 38% in cow E, 24% in cow F and 19% in cow G. The addition of an intraruminal infusion of urea gave increases in intake of ground straw of 53, 62 and 43% in cows E, F and G respectively. The amount of water drunk daily by the cows was about the same with each of the treatments when given 3·9 kg food daily; with food *ad lib.* the water drunk was related directly to the amount of food eaten (Table 3).

Table 3. *Mean daily intake of food and water drunk, rate of breakdown of cotton threads and time of retention of stained food in the alimentary tract*

Expt no.	Treatment	Mean daily intake of food (kg)	Mean daily water drunk (kg)	Rate of breakdown of cotton threads. Time for 25% loss in weight (h)	Mean time of retention of food (h)
1 (four cows)	Long dried grass restricted	4·5	27·8	24	66
	Ground dried grass restricted	4·5	25·3	28	50
	Long dried grass *ad lib.*	10·9	37·1	24	53
	Ground dried grass *ad lib.*	10·7	37·0	77*	50
	SE of difference between two means	±0·79	±0·37	—	±4·1
2 (three cows)	Long oat straw restricted	4·5	18·6	73	83
	Ground oat straw restricted	4·4	17·5	74	67
	Ground oat straw restricted +150 g urea†	4·4	20·2‡	26	51
	SE of difference between two means	—	±3·79	±21·2	±4·2
	Long oat straw *ad lib.*	5·7	22·7	79	75
	Ground oat straw *ad lib.*	7·2	27·0	169	73
	Ground oat straw *ad lib.* +150 g urea†	11·0	33·8‡	43	61
	SE of difference between two means	±0·67	±1·28	±47·5	±7·9

* Mean for three cows only (see p. 235). † Daily.
‡ Cows receiving urea also given 9 kg water by intraruminal infusion.

Digestibility

Expt 1. The mean digestibility of the organic matter of 4·5 kg long dried grass was 74·0% and of 4·5 kg ground dried grass 67·7% (Table 4) and there was a greater difference between the digestibility coefficients of the crude fibre of the foods. When food was offered *ad lib.* the digestibility of the ground dried grass was much lower than that of the long dried grass (Table 4). Differences in digestibility between individual cows were slight, except with cow D given dried grass *ad lib.* when the digestibility of the crude fibre was only 34·9%; the mean value for the other three cows was 48·6%.

Expt 2. Given an equal intake of dry matter of 3·9 kg daily the digestibility of the organic matter and crude fibre of the ground oat straw and ground oat straw with urea were lower than those of long oat straw (Table 4). The digestibility of the ground oat straw given with urea tended to be lower then that of the ground oat straw alone. With food offered *ad lib.*, the digestibilities of the organic matter (38·8%) and crude

Table 4. *Mean apparent digestibility* (%) *of the foods*

Expt no.	Treatment	Dry matter	Organic matter	Crude protein	Ether extract	Crude fibre	Nitrogen-free extract	Ash
1 (four cows)	Long dried grass restricted	67·1	74·0	75·7	33·3	74·9	74·3	27·8
	Ground dried grass restricted	64·7	67·9	64·8	46·7	57·2	71·2	48·0
	Long dried grass *ad lib.*	67·4	72·2	72·2	14·3	72·2	74·1	33·4
	Ground dried grass *ad lib.*	57·7	61·8	69·4	34·0	45·1	65·4	40·5
	SE of difference between two means	±2·11	±2·54	±6·76	±2·98	±2·65	±2·11	±4·70
2 (three cows)	Long oat straw restricted	48·4	47·9	−1·9	53·0	58·3	40·3	52·4
	Ground oat straw restricted	39·5	38·6	−7·2	53·3	40·5	39·3	43·5
	Ground oat straw restricted + 150 g urea*	37·0	35·5	68·8	52·1	35·1	39·2	47·9
	SE of difference between two means	±5·56	±6·42	±4·26	±7·48	±8·78	±3·28	±4·41
	Long oat straw *ad lib.*	43·7	43·2	−1·7	35·1	54·1	35·7	48·8
	Ground oat straw *ad lib.*	38·4	38·8	14·3	46·2	42·4	38·0	35·1
	Ground oat straw *ad lib.* + 150 g urea*	43·7	43·4	66·0	45·2	45·5	43·8	48·3
	SE of difference between two means	±0·71	±0·66	±4·48	±6·67	±2·59	±1·30	±5·55

* Daily.

Table 5. *Mean apparent digestibility of the foods in the reticulo-rumen and in the remainder of the alimentary tract*

		Digestibility (%) in the reticulo-rumen			Digestibility (%) in remainder of alimentary tract		
Expt no.	Treatment	Organic matter	Crude fibre	Nitrogen-free extract	Organic matter	Crude fibre	Nitrogen-free extract
1 (four cows)	Long dried grass restricted	41·3	47·2	47·4	32·7	27·7	26·9
	Ground dried grass restricted	28·8	37·1	44·4	39·1	20·1	26·8
	Long dried grass *ad lib.*	36·4	50·8	40·1	35·8	21·4	34·0
	Ground dried grass *ad lib.*	20·2	22·2	45·9	41·6	22·9	19·5
	SE of difference between two means	±5·40	±5·66	±8·30	—	—	—
2 (three cows)	Long oat straw restricted	23·6	31·3	14·9	24·3	27·0	25·4
	Ground oat straw restricted	20·3	33·0	24·1	18·3	18·5	15·2
	Ground oat straw restricted + 150 g urea*	10·3	13·6	15·5	25·2	21·5	23·7
	SE of difference between two means	±8·84	±15·93	±11·62	—	—	—
2 (cow F only)	Long oat straw *ad lib.*	20·1	30·8	12·4	26·1	28·3	23·8
	Ground oat straw *ad lib.*	12·6	17·5	16·7	26·1	27·4	19·4
	Ground oat straw *ad lib.* + 150 g urea*	25·0	30·8	26·5	23·4	20·1	23·3

* Daily.

fibre (42·4 %) of the ground oat straw were lower than those (43·2 and 54·1 % respectively) of the long oat straw; the digestibility of the organic matter of the ground oat straw with urea was about the same as that of long straw. There were no consistent differences between the digestibility of the diet in the three cows.

Digestion in the reticulo-rumen

Expt 1. At both levels of feeding the extent of digestion in the reticulo-rumen of the organic matter and crude fibre of the ground dried grass was considerably lower than that of the long dried grass (Table 5). Cow D digested in the reticulo-rumen only 6·8 % of the crude fibre of the ground dried grass offered *ad lib.*

The extent of digestion of each food in the hind gut was determined by difference and the results are given in Table 5; these results show that the digestibility of the diets of ground dried grass were higher than those of long dried grass.

Expt 2. At the restricted level of feeding the mean digestibility coefficient in the reticulo-rumen of the organic matter in long oat straw was 23·6 %, of ground oat straw 20·3 % and only 10·3 % when urea was infused into cows receiving ground oat straw (Table 5). Similarly, the extent of the digestion in the reticulo-rumen of crude fibre of long and ground oat straw was about the same and much higher than that of the diet of ground oat straw with urea.

In cow F when offered food *ad lib.* the digestibility of the organic matter, crude fibre and nitrogen-free extract of the long oat straw and ground oat straw with urea were about the same and much lower with the diet of ground oat straw alone (Table 5).

The extent of digestion in the hind gut was determined by difference and is shown in Table 5.

Rate of breakdown of cotton thread

Expt 1. The mean times for 25 % loss of weight of coils of cotton thread placed in the ventral sac of the rumen were 24 and 28 h with diets of 4·5 kg long and ground dried grass respectively (Table 3). When given food *ad lib.* the mean time for 25 % loss of thread was 24 h with long dried grass and with ground dried grass the mean time in cows A, B and C was 77 h; in cow D a loss in weight of only 13 % occurred in 200 h.

Expt 2. When 3·9 kg food dry matter was given daily, the mean times for 25 % loss of weight of cotton thread were 73 and 74 h with long and ground oat straw respectively and 26 h with the diet of ground oat straw with urea (Table 3). When food was given *ad lib.* the mean times for 25 % loss of weight of cotton thread increased to 79, 169 and 69 h with diets of long oat straw, ground oat straw and ground oat straw with urea respectively. Differences between individual cows in the rate of breakdown of cotton thread were small.

Mean time of retention of undigested residues

Expt 1. On average, undigested stained food residues were retained in the alimentary tract for 66 h with 4·5 kg long dried grass and for only 50 h with 4·5 kg ground dried grass (Table 3). At the higher level of feeding there was little difference between the

mean times of retention of the foods. The rapid initial excretion of ground dried grass is shown in Fig. 1 and was similar to that observed with ground hay (Campling *et al.* 1963). Differences between individual cows in mean times of retention were greater with the diets of ground roughage than with the long roughage; cow D tended to have the shortest time of retention of food residues on all the four diets.

Expt 2. The mean time of retention of straw residues when 3·9 kg dry matter were given daily was longest with long straw (83 h), shortest with ground straw with urea (51 h) and 67 h with ground straw (Table 3). When food was given *ad lib.* stained food residues were retained for 75 h with long oat straw and for about the same time with

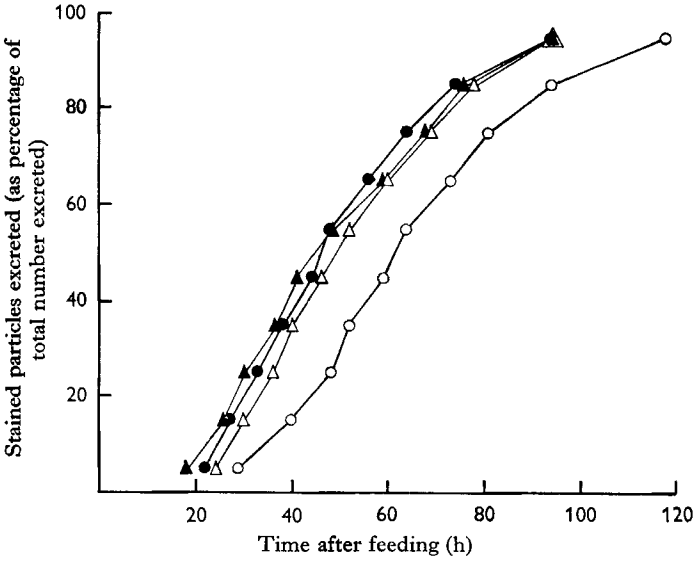

Fig. 1. Expt 1. Mean values for the excretion by cows of undigested dried grass residues at intervals after eating stained dried grass. Values are for the four cows receiving diets of 4·5 kg long dried grass (○—○), 4·5 kg ground dried grass (●—●), long dried grass *ad lib.* (△—△), and ground dried grass *ad lib.* (▲—▲).

ground oat straw (73 h) but for only 61 h with ground straw with urea. The shape of the patterns of excretion of stained residues is shown in Fig. 2, the rapid initial excretion of ground roughage is shown clearly. Although there were differences between the times of retention of stained food in the three cows, changes in retention time associated with each treatment were always in the same direction in each of the cows.

Amount of digesta in the reticulo-rumen

Expt 1. When the cows received 4·5 kg food daily, immediately before a meal there were slightly more digesta, but less digesta dry matter in the reticulo-rumen with long dried grass than with ground dried grass (Table 6). Immediately after a meal there were more digesta and digesta dry matter with 4·5 kg long dried grass than with 4·5 kg ground dried grass; this difference reflected the faster rate of loss from the reticulo-rumen of digesta dry matter derived from ground dried grass during a meal

(0·94 kg/100 min) than with long dried grass (0·88 kg/100 min). The mean rates of loss of digesta dry matter between meals were 0·28 kg/100 min with 4·5 kg long dried grass and 0·24 kg/100 min with 4·5 kg ground dried grass. When food was offered *ad lib.* there were more digesta and digesta dry matter in the reticulo-rumen immediately before a meal with ground than with long dried grass (Table 6). However, after a meal when food was offered *ad lib.* the amounts of digesta and digesta dry matter were similar with long and ground dried grass. The rates of loss of digesta dry matter from the reticulo-rumen during a meal were 0·80 kg/100 min when long dried grass was offered *ad lib.* and 1·00 kg when ground dried grass was offered.

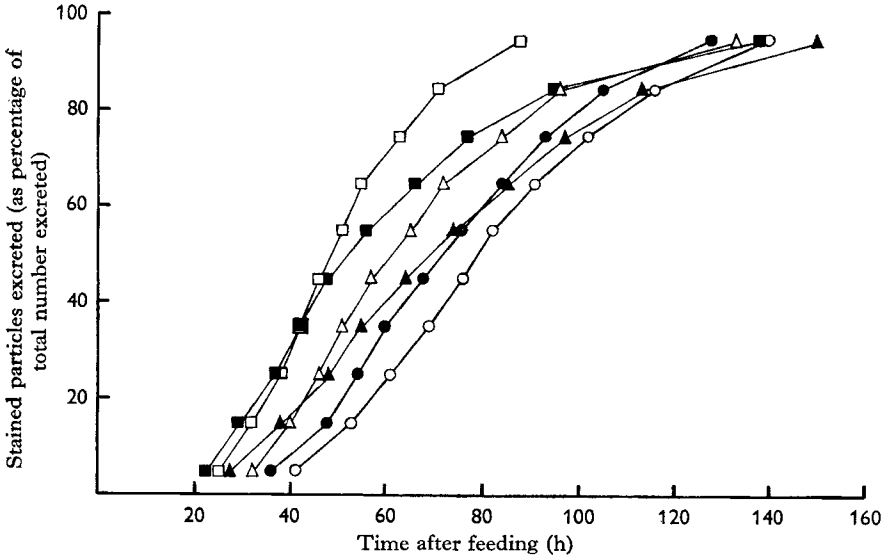

Fig. 2. Expt 2. Mean values for the excretion by cows of undigested oat straw residues at intervals after eating stained oat straw. Values are for the three cows receiving diets of 4·5 kg long oat straw (○—○), 4·5 kg ground oat straw (△—△), 4·4 kg ground oat straw with urea (□—□), long oat straw *ad lib.* (●—●), ground oat straw *ad lib.* (▲—▲), and ground oat straw *ad. lib.* with urea (■—■).

Between meals the rates of loss were 0·64 kg and 0·59 kg per 100 min with long and ground dried grass respectively. The mean dry-matter contents of the digesta were similar with each food, the highest contents of dry matter were found when food was given *ad lib.* However, at the reticulo-omasal orifice, a large difference was found between the dry-matter contents of digesta derived from long dried grass (5·1 %) and from ground dried grass (9·8 %) when these foods were offered *ad lib.* The difference between the dry-matter content of digesta was much less when 4·5 kg food were given daily, long dried grass 4·6 % and ground dried grass 6·5 %.

Expt 2. The amounts of digesta in the reticulo-rumen were measured only when the cows received food *ad lib.*, and the results are given in Table 6. In all the three cows the same trends were observed; immediately before a meal the reticulo-rumens contained on average 31 % more digesta dry matter with the diet of ground oat straw with urea than with the other two diets. The mean amounts of digesta and digesta dry

matter in the reticulo-rumen before a meal differed by only 10 and 13% respectively between long straw and ground oat straw. After a meal there was on average 49% more digesta dry matter present in the reticulo-rumen when ground oat straw with urea was offered than with the other two diets. There was a difference of only 8·7% between the amounts of digesta dry matter in the reticulo-rumen after a meal of long oat straw and of ground oat straw. The mean dry-matter contents of the digesta were about the same with the diets of long oat straw and ground oat straw and slightly higher with the diet of ground oat straw with urea. It was again observed in cow F

Table 6. *Amount of digesta in the reticulo-rumen of cows before and after feeding (kg)*

		Amount of digesta in reticulo-rumen			
		Total		Dry matter	
Expt no.	Treatment	Before feeding	After feeding	Before feeding	After feeding
1 (four cows)	Long dried grass restricted	47·1	55·6	2·80	6·70
	Ground dried grass restricted	48·1	52·8	2·21	5·58
	Long dried grass *ad lib.*	58·1	93·4	4·69	11·84
	Ground dried grass *ad lib.*	65·3	92·2	5·25	11·92
	SE of difference between two means	±4·13	±4·13	±0·438	±0·567
2 (three cows)	Long oat straw *ad lib.*	74·0	97·5	7·31	11·78
	Ground oat straw *ad lib.*	67·0	91·0	6·60	10·46
	Ground oat straw *ad lib.*+150 g urea*	83·4	119·6	9·13	16·54
	SE of difference between two means	±10·48	±14·47	±1·36	±1·34

* Daily.

when offered food *ad lib.* that, in the region of the reticulo-omasal orifice, the dry-matter content of digesta derived from the diets of ground oat straw and ground oat straw with urea was about twice (11·0%) that of the digesta derived from long straw (5·0%). Campling *et al.* (1963) found a similar large difference between the dry-matter contents of digesta by the reticulo-omasal orifice, derived from ground hay and long hay. Also, in both the present experiments and in our earlier experiment (Campling *et al.* 1963), the digesta in cows given ground roughages were a homogenous mass without the typical stratification into solid and liquid portions found when long roughages are given.

Eating and ruminating behaviour

The mean times spent eating, ruminating and resting per kg food by the cows in each experiment together with the frequency of contractions of the reticulum during each activity are given in Table 7.

Expt 1. When 4·5 kg food were given daily the ingestion of food was nearly twice as fast with ground dried grass (4·5 min/kg) as with long dried grass (8·1 min/kg). When food was offered *ad lib.* the rate of eating of ground dried grass (10·7 min/kg) was again much faster than with long dried grass (18·2 min/kg). Lower rates of eating were found when both foods were offered *ad lib.* than when the cows were given 4·5 kg daily.

The mean daily time spent ruminating per kg long dried grass was 32·9 min with the lower level of feeding and 36·9 min/kg with food *ad lib.* Although during short periods triple contractions of reticulum, normally characteristic of rumination, were observed when the cows were given ground dried grass, there were no regular jaw movements. Triple reticular contractions were not observed in cow A given ground dried grass *ad lib.* The mean daily duration of periods of triple contractions was highest, at 10 min/kg food, with the lowest intake of food.

Because of the longer time spent eating and ruminating with diets of long dried grass than with ground dried grass the cows spent considerably longer resting when given ground than when given long dried grass.

Table 7. *Mean daily time spent eating, ruminating and resting per kg food and the frequency of reticular contractions during each activity*

		Eating		Ruminating		Resting	
Expt no.	Treatment	min/kg	Contractions/100 min	min/kg	Contractions/100 min	min/kg	Contractions/100 min
1 (four cows)	Long dried grass restricted	8·1	115	32·9	98	279·4	66
	Ground dried grass restricted	4·5	174	10·0*	99	303·9	68
	Long dried grass *ad lib.*	18·2	135	36·9	91	77·8	88
	Ground dried grass *ad lib.*	10·7	121	5·2*†	99†	120·0	68
	SE of difference between two means	±1·52	±11·1	—	—	±7·05	±5·7
2 (three cows)	Long oat straw restricted	35·5	144	95·1*‡	98	189·4	112
	Ground oat straw restricted	9·4	163	17·5*‡	126‡	306·4	94
	Ground oat straw restricted + 150 g urea‖	13·4	156	19·7*	120	294·2	87
	SE of difference between two means	±1·88	±14·9	—	—	±8·21	±6·4
	Long oat straw *ad lib.*	47·2	147	93·0*§	96	121·9	117
	Ground oat straw *ad lib.*	21·8	139	12·4*§	117§	151·6	108
	Ground oat straw *ad lib.* + 150 g urea‖	16·4	142	3·2*	113	106·8	104
	SE of difference between two means	±1·64	±4·0	—	—	±13·91	±11·2

* Periods of triple contractions, jaw movements rarely observed (see above).
† Mean for cows B, C and D only. ‡ Mean for cows E and G only. § Mean for cows E and F only.
‖ Daily.

Expt 2. It was again observed at both levels of feeding that the rate of eating (min/kg food) was very much faster with ground oat straw than with long oat straw (see Table 7). At the restricted level of feeding the cows tended to eat more slowly (13·4 min/kg) when given 4·4 kg ground oat straw with urea than when given 4·4 kg ground oat straw without urea (9·4 min/kg) but when offered food *ad lib.* the cows spent longer eating per kg food with oat straw alone than when they received an infusion of urea. The infusion of urea had no effect on the frequency of contractions of the reticulum during eating.

With the diets of long straw considerable periods of rumination, amounting to 95 and 93 min/kg straw, were observed with 4·5 kg and 5·5 kg straw daily. Rumination did not occur with the diets of ground oat straw; although during short periods triple reticular contractions were seen, the concomitant regular jaw movements were absent. Triple reticular contractions were not observed in cow F given 4·4 kg ground oat straw

or in Cow G offered ground oat straw *ad lib.* Also, it was again found that the mean duration of periods of triple reticular contraction was longest with the lowest level of feeding.

The time spent resting per kg food reflected the time spent eating and ruminating and this was longer with diets of ground oat straw than with diets of long oat straw.

Estimates of the mean amounts of organic matter and digesta transferred from the reticulum to the omasum per primary contraction of the reticulum have been calculated from the weight of food eaten, the composition of digesta close to the reticulo-omasal orifice, and the extent of digestion in the reticulo-rumen. The estimates are given in Table 8 for both experiments. In Expt 2 values for cow F only are given when

Table 8. *Estimated mean weights of organic matter and digesta transferred per contraction of the reticulum from the reticulo-rumen to the omasum*

Expt no.	Treatment	Mean daily intake of organic matter (kg)	Weight of organic matter leaving reticulo-rumen/day (kg)	Total number of reticular contractions/day	Weight of material transferred from the reticulo-rumen/contraction (g)	
					Organic matter	Digesta
1 (four cows)	Long dried grass restricted	3·42	2·00	1017	2·0	60
	Ground dried grass restricted	3·35	2·38	1012	2·4	47
	Long dried grass *ad lib.*	8·41	5·35	1372	3·9	102
	Ground dried grass *ad lib.*	7·94	6·34	1049	6·0	76
2 (three cows)	Long oat straw restricted	3·54	2·70	1612	1·7	38
	Ground oat straw restricted	3·60	2·87	1402	2·0	49
	Ground oat straw + 150 g urea*	3·60	3·23	1339	2·4	52
Cow F only	Long oat straw *ad lib.*	4·74	3·50	1812	1·9	47
	Ground oat straw *ad lib.*	5·19	4·30	1648	2·6	29
	Ground oat straw *ad lib.* + 150 g urea*	8·39	6·43	1543	4·2	42

* Daily.

food was offered *ad lib.* because only in this cow were estimates made of the extent of digestion in the reticulo-rumen with all three diets; mean values for the three cows are given when they received the lower level of feeding.

Expt 1. With both levels of feeding, the amounts of organic matter estimated to have been transferred per primary reticular contraction were greater with ground dried grass (2·4 and 6·0 g) than with long dried grass (2·0 and 3·9 g). The amounts of digesta transferred per contraction showed the opposite trend, greater amounts appearing to have been transferred with diets of long than with diets of ground dried grass (see Table 8); similar results were found by Freer & Campling (1965).

Expt 2. When 3·9 kg food dry matter were given daily, a larger amount of organic matter (2·0 g) was transferred per reticular contraction with ground oat straw than with long oat straw (1·7 g); the largest amount was with the diet of ground oat straw with urea (2·4 g organic matter per contraction). The amounts of digesta transferred were related directly to the amounts of organic matter eaten (Table 8). When cow F was offered food *ad lib.* the amount of organic matter leaving the reticulum per contraction was highest with the diet of ground oat straw with urea (4·2 g) and lowest

with long oat straw (1·9 g), the amounts of digesta transferred were estimated to have been similar with the diets of long and ground oat straw with urea at 47 and 42 g respectively and only 29 g with ground oat straw.

DISCUSSION

Grinding and pelleting a roughage of high digestibility, artificially dried grass, was not associated with any change in the mean voluntary intake of food by the cows, but grinding and pelleting a roughage of low digestibility oat straw, led to an increase of 26 % in voluntary intake. These results are in agreement with the conclusion made recently in several reviews of the effects of grinding, that less benefit is obtained from grinding and pelleting a high-quality roughage than a low-quality roughage (Minson 1962; Moore, 1964; Beardsley, 1964). The intraruminal infusion of urea into cows receiving ground, pelleted oat straw *ad lib.* was associated with an increase of 53 % in voluntary intake of food by the cows. A similar effect on voluntary intake was found when urea was included in pellets of ground oat straw with molasses (F. J. van der Merwe (1964), personal communication; Greeff, van der Merwe & Swart, 1963).

In both the experiments, grinding and pelleting the roughages led to a decrease in the digestibility of the food; the depression was greater with dried grass than with oat straw. In Expt 1 when food was offered *ad lib.* the digestibility of the organic matter fell from 72 % in the long dried grass to 62 % in the ground dried grass. Similarly, in Expt 2 the digestibility of the organic matter of the diet of long oat straw *ad lib.* was 43 % and of the ground oat straw 39 %. The depressions in digestibility of the organic matter were due largely to changes in the digestibility of the crude fibre of the foods. These results agree with many reports in which cattle and sheep were given long and ground roughages (Campling *et al.* 1963; Minson, 1962; Moore, 1964; Beardsley, 1964). The depression in digestibility associated with grinding was probably due at least in part to ground roughages passing through the reticulo-rumen very quickly (Blaxter & Graham, 1956; Meyer, Gaskill, Stoewsand & Weir, 1959; O'Dell, King, Cook & Moore, 1963). Among other factors that may contribute to the low digestibility of the ground roughages, we suggested the high dry-matter content of digesta in the ventral sac of the rumen and a more rapid release and absorption of the soluble constituents of the ground than of the long roughage (Campling *et al.* 1963). The ruminal microflora of cows C and D in Expt 1 were examined when both foods were offered *ad lib.* and we are indebted to Dr C. M. Thorley for the following conclusion from this study; a full account will be published elsewhere. With long dried grass similar bacterial species were isolated in about the same numbers from both cows. With the diet of ground dried grass the numbers of cellulolytic bacteria were lower in cow D than when this cow was given long roughage, but no such difference was detected in cow C. Although in both cows the digestibility of ground roughage was less than that of long roughage, cow C digested the crude fibre of the ground dried grass to a greater extent than cow D.

In the present experiments we did not estimate directly the times of retention of food residues in the reticulo-rumen and in the hind gut. Ground roughages may well

have passed through the reticulo-rumen more quickly than long roughages. The mean times of retention of stained food residues in the whole alimentary tract varied with the level of feeding and the type of food. At the restricted level of feeding ground pelleted roughages were retained for shorter periods of time than long roughages; when food was offered *ad lib.* only a very small difference was detected between the mean times of retention of stained residues of ground and long roughages. Although these results confirm those of our preliminary experiment with ground and long hay (Campling *et al.* 1963), several workers have reported that ground roughages passed through the alimentary tract more rapidly than long roughages (Blaxter, Graham & Wainman, 1956; Meyer *et al.* 1959; Rodrigue & Allen, 1960). However, in each of these experiments the animals were given restricted amounts of food.

The mean amounts of digesta dry matter found in the reticulo-rumen immediately after a meal were similar when long and ground dried grass were offered *ad lib.* However, with ground dried grass the hind gut must have contained more digesta dry matter than with long roughage because intake was similar, the digestibility of ground roughage was lower, the time of retention in the alimentary tract was about the same and the weights of dry matter in the reticulo-rumen were similar with both foods. Thus it seems possible that under the conditions of this experiment the voluntary intake of long and ground dried grass was limited by the capacity of the reticulo-rumen at a meal, as we found in earlier experiments (Freer & Campling, 1963). The rate of disappearance from the reticulo-rumen of digesta derived from long roughages was presumably limited by the rate of breakdown of food particles in the reticulo-rumen and with ground roughages by the rate of elimination of digesta from the hind gut which directly or indirectly affects the rate of flow of digesta from the reticulo-rumen (see discussion by Campling *et al.* 1963; Phillipson & Ash, 1965). For example, it seems possible that when ground dried grass was offered *ad lib.* the high dry-matter content (9·8%) of digesta leaving the reticulo-omasal orifice may have restricted the amount of digesta leaving at each primary reticular contraction (see Table 8). The voluntary intake of long and ground oat straw in Expt 2 appeared to be regulated in a way similar to that postulated to have occurred in Expt 1. However, when intraruminal infusions of urea were given to cows receiving ground oat straw *ad lib.* the mean amount of digesta dry matter in the reticulo-rumen immediately after a meal was 49% higher than with the diets of ground oat straw alone and long oat straw (Table 6). This situation of lower amounts of dry matter in the reticulo-rumen with long and ground oat straw than with ground oat straw with urea may be similar to that observed by us when we found, immediately after a meal, 35% less digesta dry matter in the reticulo-rumen of cows offered long oat straw than when offered long hay (Campling *et al.* 1962). Also, it is known that when the three cows used in Expt 2 were offered medium-quality long hay *ad lib.* under similar conditions to those of Expt 2 the mean amounts of digesta and digesta dry matter in the reticulo-rumen immediately after a meal were 115 and 15·6 kg respectively; these amounts are about the same as those found with the diet of ground oat straw with urea in the present experiment (see Table 6). Thus it seems that with oat straw the low content of protein restricted the voluntary intake of this food by cattle, that the daily intraruminal infusion of urea

compensated for the low protein content, and that this permitted the amount of digesta in the reticulo-rumen during a meal to increase to the amount found with higher-quality roughages. It is well known that a deficiency of protein in the diet of an animal limits its voluntary intake of food, and Egan (1965) showed that the daily administration of casein directly into the duodenum of sheep caused an increase in voluntary intake of low-protein roughages which could not be explained by the increased digestion and shorter time of retention of food residues in the gut. Also, it was estimated that the amount of material in the digestive tract increased considerably when casein was administered.

The eating and ruminating behaviour of the cows was altered appreciably by the diets of ground roughages (Table 7). The much faster rate of eating of ground, pelleted roughages compared with long roughages, and the absence of rumination and presence of short periods of triple reticular contractions when the cows were given ground roughages confirm earlier findings; see summary by Ruckebusch & Marquet (1963) and of our preliminary observation with ground, pelleted hay (Freer & Campling, 1965).

In conclusion, the results given in this series of reports on the factors affecting the voluntary intake of food by non-lactating cows have emphasized the importance of the amount of digesta in the reticulo-rumen and their rate of disappearance from this organ in controlling the voluntary intake of long roughages such as hay and dried grass. However, with ground pelleted roughages it was shown that the amount of digesta in the hind gut may have exerted an indirect effect on voluntary intake by limiting the rate of disappearance of digesta from the reticulo-rumen. The voluntary intake of concentrates was not related in the same way as that of long roughage to the amount of digesta in the reticulo-rumen as the amount of digesta did not approach the amount found with roughages (Freer & Campling, 1963).

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