Importance of palatability in determining the feed intake of sheep offered chopped and pelleted hay

BY A. I. VAN NIEKERK,* J. F. D. GREENHALGH AND G. W. REID
Rowett Research Institute, Bucksburn, Aberdeen AB2 9SB

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1. In the first of three experiments four sheep received chopped (C) and pelleted (P) hay by mouth (m) or rumen fistula (f) in the four combinations shown below. Feed eaten by mouth was offered *ad lib.* from 09.15 to 16.00 hours; feed was given by fistula at 09.00 hours in amounts equal to half of total intake (i.e. by mouth and by fistula) on the previous day. Daily dry-matter intake (g/kg metabolic live weight, $W^{0.75}$) was as follows: treatment C_mC_f, 51·5; C_mP_f, 74·5; P_mC_f, 57·8; P_mP_f, 85·7. The corresponding dry-matter digestibility coefficients were 0·59, 0·56, 0·57 and 0·53.

2. The intention was that the difference in intake between C_mP_f and P_mC_f should provide a measure of palatability, since the animals digested the same composite diet but ate different components of it. For the comparison to be valid the two treatments had to promote equal rates of digestion, but measurements of rumen fill and of rate of passage of digesta suggested that C_f was digested more slowly than C_m.

3. In Expt 2, each form of hay was given entirely by mouth or partly by fistula. Daily dry-matter intake (g/kg $W^{0.75}$) was as follows: C_m, 45·5; C_mC_f, 42·4; P_m, 80·4; P_mP_f, 79·2. In this experiment there was less evidence of C_f being digested more slowly and hence depressing intake.

4. The conclusion drawn from these two experiments is that fistula feeding in its present form is not a suitable technique for measuring the relative palatability of feeds differing considerably in physical structure. However, the technique might be improved if food given by rumen fistula to one animal was previously masticated by, and collected from the oesophageal fistula of, a second animal.

5. In Expt 3, the effects of sudden changes from a composite diet to either C or P, or from C to P or vice versa were measured in sheep receiving food by mouth only. The patterns of intake suggested that total intake might be partially determined by feed palatability.

Grinding and pelleting a roughage generally increases the quantity voluntarily consumed by ruminants, although the increase depends on the quality of the roughage and the species of animal (Greenhalgh & Wainman, 1972). The usual explanation for the increase is that pelleted roughage spends less time in the reticulo-rumen, because its particles are small enough to enter the omasum without further comminution, and the potential throughput of the reticulo-rumen is thus increased. This explanation hinges on the finding that in animals given equal quantities of long or pelleted roughage the quantity of dry matter in the rumen (rumen load) is smaller with the pelleted feed, and that the rate of passage of stained feed particles through the whole digestive tract is faster (Blaxter, Graham & Wainman, 1956; Waldo, Miller, Okamoto & Moore, 1965; Campling & Freer, 1966).

An additional factor favouring a greater intake of pelleted roughage may be that it is more palatable. In particular, it is known that pelleted roughage may be eaten at a faster rate than long; for example, Campling & Freer (1966) found that cows ate long or pelleted oat straw at rates of 28 and 106 g/min respectively. It is thus possible that animals eat pellets in greater quantity partly because they can eat them more easily.

* Present address: Rusgeer, Kenhardt, South Africa.

The experiments described were intended to compare the relative palatability of long and pelleted hay. To measure the effect of palatability on intake one needs to identify and separate from it the effect on intake of the rate of digestion of the food. Two methods involving feeding partly through a rumen fistula have been used to make this separation. In one (Greenhalgh & Reid, 1967, 1971), two feeds are used; first one is eaten by mouth and the other given in equal quantity by fistula, and for a second period the two feeds are changed over. The animal thus digests the same mixture on each occasion, and any difference in intake can be attributed to the relative palatability of the two feeds. In the second method (Weston, 1966), an animal fed to appetite on a single food is given some of the same food by fistula; if its intake by mouth falls by an amount equal to that given by fistula, the conclusion drawn is that intake is limited by rate of digestion rather than by the palatability of the feed. The two methods were tested in the first two experiments described below. As neither proved to be satisfactory, further attempts to isolate the effects on intake of rate of digestion and palatability were made in a third experiment in which initial responses of sheep to abrupt changes of diet were measured. A preliminary account of part of the work has been published (Greenhalgh, 1971).

EXPERIMENTAL

Design

Expt 1. Chopped (C) and pelleted (P) forms of the same hay were compared by giving them to sheep in four combinations in a trial of 4 × 4 Latin square design. For two of the treatments the sheep ate one form to appetite (m) and had an equal amount of the same form administered through a rumen fistula (f); these treatments, designated C_mC_f and P_mP_f, measured the total effect of pelleting on intake. Treatments are coded in this way throughout the paper; the feed given by mouth always appears first in the code. For the remaining two treatments the sheep ate one form by mouth and received the other by fistula (C_mP_f and P_mC_f). With these treatments the sheep digested the same 50:50 mixture of forms but ate different components and it was thought that differences in intake would be due solely to differences in palatability.

Each period lasted 28 d and was subdivided as follows: days 1–10, preliminary feeding; 10 and 13, rumen contents measured once before and once after feeding; 15–25, intake, digestibility and rate of passage of stained particles measured; 25 and 28, rumen contents measured.

Expt 2. This also comprised a 4 × 4 Latin square trial, in which chopped and pelleted forms of hay were compared, with and without partial feeding by fistula. The treatments were therefore C_m, C_mC_f, P_m and P_mP_f. Each period lasted for 21 d, intake and digestibility being measured over the last 9 d.

Expt 3. In the first part, four sheep were given for two periods of 6 d 500 g chopped hay and 500 g pelleted hay per day, given together at a single meal. On day 7 of each period the sheep were offered *ad lib.* for 7 h either chopped or pelleted hay, and their rumen load was then measured.

In the second part of Expt 3, the same four sheep were given unrestricted access to chopped or pelleted hay for three alternating periods of 5 d. Two sheep followed the sequence *CPC* and the other two, *PCP*.

Sheep

In Expt 1 the sheep were Scottish Half-bred (Border Leicester × Cheviot) castrated males, initially 8 months old and fitted with rumen cannulas (internal diameter, 50 mm). In Expt 2, two of the same animals, by then aged 3 years, were used, together with two Greyface (Border Leicester × Scottish Blackface) castrated males aged 5 years. For Expt 3, one Half-bred and three Greyfaces were used. The sheep were kept in individual pens with sawdust litter (which they were not observed to eat) and were treated periodically for intestinal parasites.

Feeds and feeding procedure

Two separate but similar lots of meadow hay were used, the first for Expt 1 and the second for Expts 2 and 3. The first lot contained 100 g crude protein and 935 g organic matter/kg dry matter, and the second 84 g crude protein and 928 g organic matter. The chopped forms were prepared with a chaff cutter giving lengths of about 20 mm, and the pelleted forms with a hammer mill having a 1·6 mm screen and a press with a 16 mm die. For Expt 1 the first batch of pellets was made without an additive and the pellets were rather soft and unstable. A further batch of harder pellets was made by including 20 g Fuller's earth/kg. In a subsidiary trial the two batches were found to promote equal voluntary intakes in sheep.

The feeding procedure was that described previously (Greenhalgh & Reid, 1971). Briefly, at 09.00 hours each day the sheep received food by fistula in a quantity equal to half the total intake – by mouth and by fistula – of the previous day. Chopped hay given by fistula was moistened with four times its weight of warm water; pellets were inserted dry, but water in the proportion used for chopped hay was then poured into the rumen. After their fistula feed the sheep had access to the feed taken by mouth until 16.00 hours.

Techniques

The digestibility of the feeds, the rate of passage of digesta and rumen contents were measured by the methods described previously (Greenhalgh & Reid, 1971). Portions of the chopped and pelleted feeds were stained with basic fuchsin and brilliant green. In period 1 of Expt 1 it was noted that particles stained with brilliant green tended to lose their colour, and for subsequent periods the dye was fixed by soaking the particles in a solution of tannic acid (40 g/l). In each period, on the last of the four occasions when the rumen was emptied, its volume was measured by filling it with warm water. The volume was calculated as the mean of the volumes of water added and removed.

RESULTS

Expt 1

Feed intake and digestibility. The total effects of pelleting (C_mC_f *v.* P_mP_f) were large and significant, digestibility of dry and organic matter being depressed by 0·06–0·07 and intake increased by about 70% (Table 1). Secondly, changing the nature of

Table 1. *Expt* 1. *Digestibility and intake of chopped* (C) *and pelleted* (P) *hay when ingested by mouth* (m) *or fistula* (f)

(Mean values for four sheep)

Treatment	Feed consumed			Digestibility ratio		Daily intake		
	Orally	Intraruminally*		Dry matter	Organic matter	Dry matter (g)	Dry matter (g/kg $W^{0.75}$)†	Organic matter (g/kg $W^{0.75}$)†
C_mC_f	*C*	*C*	(0.48)	0.59	0.61	1052	51.5	47.4
C_mP_f	*C*	*P*	(0.50)	0.56	0.57	1554	74.5	68.5
P_mC_f	*P*	*C*	(0.48)	0.57	0.58	1243	57.8	53.1
P_mP_f	*P*	*P*	(0.49)	0.53	0.54	1804	85.7	78.6
SE of differences	—	—	—	0.013	0.010	96	4.41	4.05

* Values in parentheses are proportions of total dry-matter intake given intraruminally.
† *W*, live weight before feeding.

Table 2. *Expt* 1. *Weights of the sheep, their rumen volume and the weights of rumen contents before and after feeding with chopped* (C) *and pelleted* (P) *hay, by mouth* (m) *or fistula* (f)

(Mean values for four sheep)

Treatment ...	C_mC_f	C_mP_f	P_mC_f	P_mP_f	SE of differences
Wt of sheep with empty rumen (kg):					
Before feeding	47·0	48·6	50·2	50·6	0·56
After feeding	45·8	48·1	49·3	50·9	0·55
Rumen volume (l)	19·8	18·0	18·8	16·8	0·86
Total rumen contents (kg):					
Before feeding	9·11	8·58	9·05	7·18	0·31
After feeding	12·47	11·85	13·70	11·64	0·93
Dry matter in rumen (g):					
Before feeding	777	745	784	635	62
After feeding	1472	1634	1731	1638	110
Dry matter consumed in previous 24 h (g)	1018	1599	1292	1830	90
Disappearance of dry matter from rumen (g/h):					
During feeding (7 h)	46·2	94·3	49·3	117·5	9·6
Between feeds (17 h)	40·8	52·4	55·7	59·3	3·3

the food digested without changing the nature of that eaten (C_mC_f *v.* C_mP_f and P_mC_f *v.* P_mP_f) also had large effects of the kind expected; in both instances changing the fistula feed from chopped hay to pellets caused digestibility to fall by 0·03–0·04 and intake to increase by about 45%. Changing the nature of the food eaten without changing the mixture digested (C_mP_f *v.* P_mC_f) had no significant effect on digestibility and affected intake markedly but not in the direction expected. Thus intake was about 26% higher for C_mP_f than for P_mC_f, which suggested that chopped hay was more palatable than pelleted. However, the superiority of C_mP_f to P_mC_f varied considerably between sheep, the extremes being 5 and 63%.

Rumen contents. Table 2 summarizes the results for the rumen contents of the sheep and some associated measurements. Each value for rumen contents is a mean of eight observations, two for each sheep. Before feeding, both total (wet) and dry contents were significantly greater for C_mC_f than for P_mP_f. After feeding, the highest values for both wet and dry matter were those for P_mC_f, even though intake on this treatment was lower than on C_mP_f. The water-filled volume of the rumen was related to the proportion of chopped hay in the diet rather than to the weight of food consumed. Thus rumen volume was significantly greater for treatment C_mC_f than for C_mP_f, though intake was lower for the former treatment, and rumen volume was similarly greater for P_mC_f than for P_mP_f.

The mean quantities of dry matter consumed in the 24 h preceding the removal of rumen contents were within 4% of the 10 d measurements of intake (Table 1), and the weights of rumen contents recorded may, therefore, be assumed to be representative of those obtained during the 10 d period. The rates of disappearance of dry matter from the rumen were calculated from rumen contents and intake. For example, for C_mC_f the rate during the 7 h feeding period was calculated as (777 + 1018 − 1472)/7 = 46·2 g/h and that between meals as (1472 − 777)/17 = 40·8 g/h. When pellets

Table 3. *Expt* 1. *Mean retention time of stained particles given by fistula in sheep ingesting chopped* (C) *or pelleted* (P) *hay, by mouth* (m) *or fistula* (f)

(Mean values for four sheep)

	Observed retention time (h)				Adjusted retention time (h)*		
	Chopped		Pelleted				
Treatment	Green	Red	Green	Red	Chopped	Pelleted	Mean†
C_mC_f	56	66	—	—	61	—	61
C_mP_f	—	58	34	—	53	38	45
P_mC_f	54	—	—	51	59	47	53
P_mP_f	—	—	33	41	—	37	37

* See below.
† SE of differences = 1·7.

were given by fistula, the rate of disappearance was much faster during meals than between them. When chopped hay was given by fistula, this was not so, and for P_mC_f the rate during feeding was actually lower than that between meals.

Rate of passage. The faeces generally contained more red (fuchsin-stained) particles than green. The disparity was extremely large in period 1, the average ratio of red to green being 43:1. In subsequent periods, when the green dye had been fixed with tannic acid, the ratio was on average 2:1. When the sheep were given particles of the same feed stained both red and green (treatments C_mC_f and P_mP_f), the retention time calculated from green particles was lower than that calculated from red particles (Table 3). For chopped hay the mean difference was 10 h and for pelleted, 8 h. All the retention times were therefore adjusted by adding 5 and 4 h respectively to values calculated from chopped and pelleted particles stained green, and by deducting these times from the values for red particles; the adjusted values are included in Table 3.

Chopped and pelleted particles had distinctly different retention times, and within each type the time was inversely proportional to the total quantity of feed ingested.

Expt 2

Mean values for intake and digestibility are shown in Table 4. For both pelleted and chopped hay voluntary intake was reduced slightly by feeding partly by fistula, but in neither instance was the difference significant.

Expt 3

The effects on intake of changing sheep from a restricted ration of chopped and pelleted hay to unrestricted amounts of either of them (Expt 3 (*a*)) are shown in Fig. 1. Over a 7 h period the sheep changed to pelleted hay ate 400 g (30%) more than those changed to chopped, virtually all the difference arising in the 1st hour. At the end of the 7 h, the former had more dry matter in the rumen than the latter (1910 *v.* 1820 g), but the difference was only 22% of the difference in dry-matter intake. This indicates that even in the short period of 7 h the change of diet had induced changes in the rate of digestion in, or passage from, the rumen.

Table 4. *Expt 2. Digestibility and intake of chopped* (C) *and pelleted* (P) *hay when ingested entirely by mouth* (m) *or partly by fistula* (f)

(Mean values for four sheep)

Treatment	Feed consumed: Orally	Feed consumed: Intraruminally*		Digestibility ratio: Dry matter	Digestibility ratio: Organic matter	Daily intake: Dry matter (g)	Daily intake: Dry matter (g/kg $W^{0.75}$)†	Daily intake: Organic matter (g/kg $W^{0.75}$)†
C_m	C	—		0·56	0·58	1041	45·5	42·9
C_mC_f	C	C	(0·52)	0·59	0·60	973	42·4	40·0
P_m	P	—		0·51	0·53	1896	80·4	77·5
P_mP_f	P	P	(0·50)	0·52	0·55	1840	79·2	76·4
SE of differences	—	—	—	0·009	0·010	130	5·07	4·93

* Values in parentheses are proportions of total dry-matter intake given intraruminally.
† W, live weight before feeding.

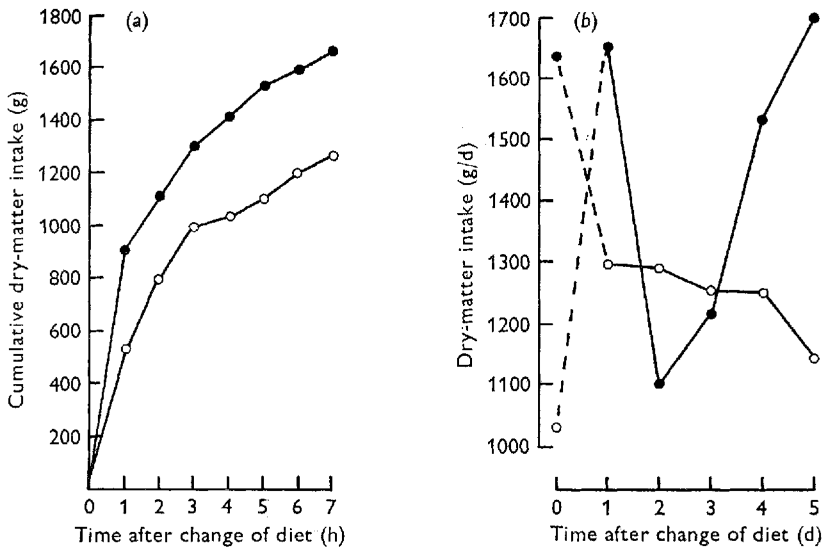

Fig. 1. Expt 3. Intake patterns of sheep after (*a*) a change from restricted, equal quantities of chopped and pelleted hay to one or other feed eaten to appetite, (*b*) a change from chopped hay to pelleted or vice versa. ○, chopped hay; ●, pelleted hay.

When sheep were given unrestricted access to pelleted hay and then changed to chopped hay, there was an immediate reduction in intake on the 1st day, followed by a further gradual fall for the next 3 d (Fig. 1 (*b*)). When the change was from chopped to pelleted, however, an immediate rise in intake was followed by an almost equally large reduction on the 2nd day and then by a rapid rise over the last 3 d.

DISCUSSION

Before drawing any conclusions about the relative palatability of the two forms of hay we have to decide whether the comparisons made provided a satisfactory measure of palatability. For Expt 1 it is essential first that the two mixed-feed treatments (C_mP_f and P_mC_f) should have the same composition (i.e. each component should contribute half of total intake) and secondly, that rate of digestion should be the same for the two treatments. The first condition was met, in that the mean ratio of one form to the other did not exceed 1:1·08 (and that for individual animals did not exceed 1:1·13). The second condition, however, was probably not met, since the two treatments appeared to produce different conditions in the rumen. Although intake for treatment P_mC_f was only 80% of that for C_mP_f, weights of rumen contents, both before and after feeding, were higher for the former treatment (although not significantly higher). The greatest difference between the treatments was in the rate of disappearance of dry matter from the rumen during feeding, this being twice as great for C_mP_f as for P_mC_f. It was noticed that the rumen contents of the sheep when receiving treatment P_mC_f formed a uniform dense mat of fibrous material which was difficult to withdraw; with C_mP_f, on the other hand, the rumen contents showed the usual stratification, with coarser material uppermost, and were more easily removed. The two treatments differed in the rate of passage of stained particles, but only to an extent commensurate with the difference between them in intake. However, these particles were always given by fistula and their rates of passage could therefore not be expected to reflect a difference in the rate of digestion of the same material ingested by different pathways.

It seems, therefore, that when chopped material is inserted into the rumen its digestion is delayed initially, presumably because it is not chewed until rumination occurs. Thus Expt 1 did not provide a satisfactory measure of the relative palatability of the two forms because treatments C_mP_f and P_mC_f differed in respects other than the nature of the food eaten. Bailey & Balch (1961) found that if cows were given the same ration of hay (6·4 kg/d) either entirely by mouth or entirely by rumen fistula, the quantity of dry matter in the rumen was 22% greater after feeding by fistula.

In Expt 2, in which the same feed was given entirely by mouth or partly by fistula, feed given by fistula caused intake by mouth to fall by a slightly greater amount; therefore the conclusion drawn is that for neither form of hay was palatability an important determinant of intake. This result does not agree with that of Expt 1 since, if fistula feeding with chopped hay delays its digestion, the results expected for Expt 2 would be that fistula feeding would depress intake of chopped hay by a considerable amount (and probably not affect intake of pelleted hay). Thus Expt 2 can be interpreted in two ways, as a test of the effects of fistula feeding on intake or as a test of palatability, and for this reason must be regarded as unsatisfactory. To put this another way, if the intake of a food is limited by its palatability, any increase in total intake achieved by partial feeding by fistula (Weston, 1966) may be nullified by the effects of fistula feeding on rate of digestion.

Weston (1966) coarsely milled all the feed given by fistula in order to avoid any delay in digestion, and his comparison was therefore of the kind, C_m *v.* C_mP_f. In the present work this comparison can be made only by combining the results of the two experiments. The general levels of intake in the two experiments were comparable as the two treatments common to both gave similar absolute intakes, the mean values for C_mC_f being 1052 g dry matter/d in Expt 1 and 973 g in Expt 2, and for P_mP_f, 1804 and 1840 g respectively. However, intake for treatment C_mP_f in Expt 1 (1554 g dry matter/d) was considerably greater than that for treatment C_m in Expt 2 which suggests that if Weston's technique had been used to examine chopped hay the conclusion would have been that intake was limited by palatability, but a further experiment is needed to confirm this.

The weights of rumen contents provide further evidence on the importance of palatability as a determinant of intake, for if animals given different diets maintain a constant weight of contents, then the main factor determining intake is more likely to be physical distention than palatability. Rumen contents measured immediately after feeding are likely to represent maximum capacity and at this time the differences between treatments in total rumen contents or dry matter were, in general, non-significant. This agrees with the finding of Ulyatt, Blaxter & McDonald (1967), that sheep eating various roughages to appetite had equal volumes of rumen liquor, even though their intakes differed. In contrast, we found earlier that when sheep were fed on dried grass or oat straw, and palatability appeared to influence intake, weights of rumen contents were considerably lower when straw was eaten (Greenhalgh & Reid, 1971). A further point of interest concerning rumen contents after feeding was that their weight per unit of water-filled volume tended to be higher when the diet contained pellets. For rumen dry matter the respective values (g/l) were: C_mC_f, 74·3; C_mP_f, 90·8; P_mC_f, 92·0; P_mP_f, 97·5.

Before feeding, both total contents and dry matter were about 20% lower for treatment P_mP_f than for the other three treatments. The difference was significant for total contents and it presumably reflects the faster passage of ground feed from the rumen.

Expt 3 provided an alternative approach to the problem of separating the effects on intake of palatability and of rate of digestion. We thought that if animals were well accustomed to two feeds their initial response to a change to one or other of these feeds would give a measure of relative palatability, since the 'feedback' effects of rumen contents would be initially the same for the two feeds.

In Expt 3 (*a*) animals were fed on a two-component diet which was presumed to produce a uniform weight of rumen contents and were then changed to either one component or the other. The immediate response (i.e. in the 1st hour) was for intake to be 70% higher for pellets, and the difference may have been due to easier prehension of pellets (ease of prehension being one component of palatability). Within a relatively short time, however, the different treatments had led to differences in the weight of rumen contents and also in rate of disappearance from the rumen (since the difference in rumen contents was less than the difference in intake). Thus the 'feedback' effects of rumen contents and rate of digestion occur so quickly that they may obscure any effect of palatability. Expt 3 (*b*) was intended to measure the instantaneous effect of changing from one form of feed to the other. It was argued that an animal changed from pelleted to chopped hay would start with the advantage of low weight of rumen contents and that this advantage would gradually be lost as the rumen contents changed to those resulting from the consumption of chopped hay. Intake could thus be expected to show a gradual decline until a new equilibrium was established. Conversely, an animal changed from chopped to pelleted hay would show a gradual increase in intake.

In fact, neither change of diet caused a gradual change in intake. When changed from chopped to pelleted hay the sheep achieved an immediate and large increase in intake, in spite of the initial disadvantage of having the residues of chopped hay in their rumens, and this is interpreted as evidence for the pelleted feed being more palatable. Indeed the pattern of intake following the change to pelleted hay suggests that on the 1st day the sheep found the pellets so palatable that they ate more than they were capable of digesting and thus had to eat less on the 2nd day. The immediate reduction in intake which followed the change from pelleted to chopped hay also provides evidence for the greater palatability of the former.

Of the three experiments, only the last provided satisfactory evidence for the difference in intake between the feeds being due in part to a difference in palatability. The technique of partial feeding by fistula used in the first two experiments seems to be unsatisfactory for comparing the palatability of foods differing so much in physical form. The technique would perhaps be improved if the feed given by rumen fistula to one animal was first ingested, chewed and swallowed by a second animal and then collected from an oesophageal fistula.

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