The rate of passage of foodstuffs through the alimentary tract of the goat

1. Studies on adult animals fed on hay and concentrates

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Although the goat is frequently used in work on ruminant digestion, the information I could trace on the rate of passage of foodstuffs through the alimentary tract is confined to that of Columbus (1936), who investigated this problem in one goat and one kid, and Biondo (1953) who used four goats and four kids. More attention has been paid to measuring the rate of passage in other ruminants, commencing with the work of Réaumur and Spallanzani in the eighteenth century. Recent workers in this field include Usuelli (1933) and Balch (1950) who worked with cattle, and Falaschini (cited by Biondo, 1953), Columbus (1936) and Lenkeit (1930, 1932) who used sheep.

The techniques employed have usually involved the feeding of a stained marker such as oats (Lenkeit, 1930, 1932; Falaschini; Usuelli, 1933; Biondo, 1953), straw (Columbus, 1936) or hay (Balch, 1950), undigested particles of which could be recognized in faeces collected at specified intervals. The rate of passage of the marker was determined, either by merely counting the coloured particles (Lenkeit, 1930, 1932; Columbus, 1936; Balch, 1950), or by counting and weighing them (Falaschini; Usuelli, 1933), or by simply measuring the time of their first and last appearance (Biondo, 1953).

The widely different techniques employed by the various authors make it difficult to compare their results. Variations in physical form and digestibility between such markers as oats, hay and straw are likely to affect the results obtained. For example, Balch (1950) has shown that ground hay and cereal husks pass through the alimentary tract much more rapidly than long hay.

Because of the lack of information concerning the rate of passage of food in the goat, a series of experiments was carried out on adult goats fed on a diet of hay and concentrates and the results obtained are reported in this paper.

METHODS

Experimental animals

Two experiments (*A* and *B*) were conducted on each of eight adult goats of the Saanen breed, selected to give a wide range of body-weights (26·6–57·3 kg). All were castrated males except for goats nos. 3 and 5 which were females. During the period of each experiment and for the 10 preceding days the goats were confined in crates, which were designed to facilitate the collection of urine-free faeces and food remnants. Throughout the experimental and preliminary periods the animals were fed a daily ration of 400 g of calf nuts (20% crude protein, 7·5% crude fibre) and medium-quality meadow hay *ad lib*. The allowance of concentrates was invariably eaten. Refusals of hay were weighed daily.

All the goats were weighed weekly. They were also weighed on the 4th day of each experiment, and this weight was taken as the weight over the whole experiment.

Technique for measuring rate of passage

The technique employed, which was based on the method developed by Balch (1950), consisted of feeding a small meal of stained meadow hay and counting the coloured particles found in the faeces. The hay was stained with either basic fuchsin or brilliant green, these two stains having been found in preliminary experiments to be the most suitable for work with goats. The hay was boiled for half an hour in a 0·025% aqueous solution of the stain, washed well in running water, and then boiled in fresh water. After a second washing and boiling the hay was finally washed and dried.

For each experiment goats were given 10–20 g of this coloured hay between 9.20 and 9.40 p.m. For the purpose of calculation 9.30 p.m. was taken as the time of feeding. Faeces were collected 11 h later, and then every hour until the first stained particles were recognized. Subsequent collections were made every 4 h for the next 2 days, and then at intervals which became progressively longer until no more particles could be detected in the faeces.

The faecal pellets from each collection were well broken up and mixed, and a 5–10 g sample was removed for a dry-matter determination. Another sample of about 40 g was also taken and mixed with enough water to make a thick paste. Samples of this paste were used for the 'particle count'. A teaspoonful of paste was placed on each of four squares of double thickness surgical gauze stretched over an embroidery frame, and the faeces were distributed evenly by washing with a flattened jet of water. The gauzes were then placed on a white dinner plate ruled in squares and the coloured particles counted under constant conditions of artificial illumination. Each series of four gauzes had been previously dried and weighed together and, after the count, they were again dried at 100° to constant weight to enable the amount of dry faecal residue on them to be determined. The weight of dried residue on the four gauzes varied between 0·30 and 0·50 g, and was found by experiment to be proportional to the weight of faecal dry matter originally placed on the gauze in the form of wet faeces. The particle count was expressed as the number of particles per g dried faecal residue, and the total number of coloured particles excreted over each collection period was calculated. The number of particles excreted up to any given time was then expressed as a percentage of the total number excreted over the whole period of the experiment. These cumulative totals were plotted against time to give excretion curves, three typical examples of which are given in Fig. 1.

Two measurements (Exps. *A* and *B*) of rate of passage of stained hay were made for each goat, either in consecutive weeks or with an interval of 1 week.

Interpretation of results

When the results were expressed merely as excretion curves precise comparisons between experiments were difficult, and no values were available for statistical analysis. Thus though it was possible to compare individual points on the curves, such as the times of 5, 50 and 80% excretion (see Balch, 1950), no single points could give an adequate indication of the shape of the curve over its entire course.

In order to compare the curves along their entire lengths, a value termed '*R*' which was directly proportional to the area to the left of the curves was calculated by adding

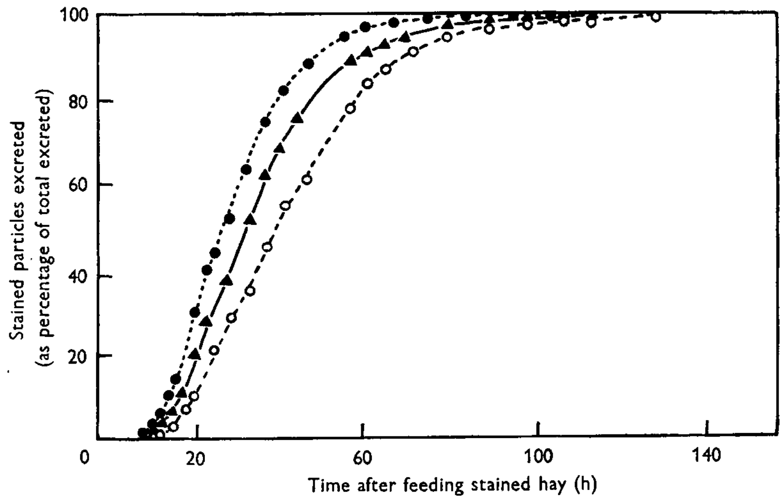

Fig. 1. Rates of excretion of undigested residues of stained hay in two experiments (*A* and *B*) on each of eight adult goats. ▲—▲, mean values of all sixteen measurements (*R** = 38·0 h); ● - - - ●, goat no. 2, Exp. *A* (*R* = 32·2 h); ○ - - - ○, goat no. 4, Exp. *B* (*R* = 44·8 h).

* See this page.

together the times of excretion from 5 to 95% at intervals of 10%, taken from the graph, and dividing the sum by 10 (Fig. 2). This value was taken as a measure of the mean retention time, in h, of the stained particles in the alimentary tract.

RESULTS

R *values and excretion times*

The results of the measurements of rate of passage of stained hay obtained for each goat are shown in Table 1, *A* and *B*.

In all the goats in both experiments the stained particles were first detected in the faeces between 11 and 15 h after feeding the coloured hay. Their concentration in the faeces then rose sharply and reached a maximum at approximately 30 h after feeding. From then onwards the numbers of particles gradually fell: they had usually completely disappeared by the 6th or 7th day (Fig. 3).

Excretion curves for each experiment showed the same general sigmoid shape. After a slow initial rise to a level of about 5% excretion, the curves rose sharply to the

80% point and gradually flattened in the final stages of excretion (Fig. 1). Between the times of 5 and 80% excretion, coloured particles were excreted at an average rate of 2·1%/h, the values varying between 1·6 and 2·8% in different animals. From Table 1 it can be seen that the R values for the sixteen experiments ranged from 32·2 to

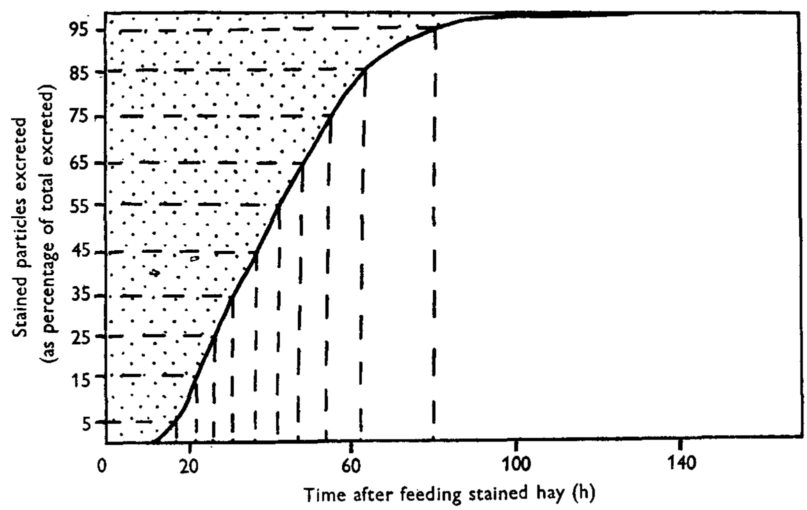

Fig. 2. Curve of excretion of undigested residue of stained hay by an adult goat showing method of calculation of the R value (see p. 17).

Table 1. *Body-weights; times of mean retention* (R)*, 5% *excretion*† *and* 95% *excretion*† *of stained hay; food intake/kg body-weight and food intake/(kg body-weight)*$^{\frac{3}{4}}$; *dry-matter content of faeces, measured in two experiments on each of eight goats*

No. of goat	Exp.	Body-weight (kg)	Time (h) of: Mean retention (R)	Time (h) of: 5% excretion	Time (h) of: 95% excretion	Food intake: g/day/kg body-weight	Food intake: g/day/(kg body-weight)$^{\frac{3}{4}}$	Dry-matter content of faeces (%)
1	*A*	34·9	35·8	16·0	65·0	30·2	99·5	32·6
	B	35·0	35·2	17·0	64·0	31·9	104·5	38·6
2	*A*	33·0	32·2	15·5	60·0	35·5	113·8	38·7
	B	33·3	33·8	15·5	69·0	34·4	110·7	40·7
3	*A*	34·2	36·2	13·5	78·0	35·2	114·1	33·6
	B	34·9	37·5	16·5	78·0	34·5	112·6	38·0
4	*A*	36·1	40·4	16·5	82·0	28·5	94·0	39·2
	B	36·8	44·8	17·5	85·0	28·5	94·9	40·1
5	*A*	27·1	40·0	15·5	84·0	27·7	83·7	43·3
	B	26·6	44·7	18·0	87·0	28·7	86·1	44·1
6	*A*	40·0	37·8	15·5	70·5	24·7	84·5	42·9
	B	42·8	35·2	17·0	67·0	26·6	93·0	40·2
7	*A*	43·4	40·3	15·0	78·0	26·2	92·2	32·4
	B	42·5	36·3	14·0	78·0	26·6	92·4	33·7
8	*A*	54·0	37·6	18·0	72·0	22·8	86·0	42·5
	B	57·3	40·8	16·5	77·0	22·6	87·5	31·0

* See p. 17. † See Balch (1950).

44·8 h (mean 38·0 ± 3·6) (Fig. 1). Analysis of variance shows that the rate of passage varied more widely from goat to goat than within individual animals. Thus the mean square for the R values between animals (7 D.F.) is 21·8, whereas within animals (8 D.F.) it is only 4·9.

Most workers have given the times of first and last appearance of the coloured marker in the faeces. Both these values, however, are very difficult to measure with any precision, since they depend on the detection and counting of very small numbers of particles, and require collection of faeces at very short intervals. It was therefore

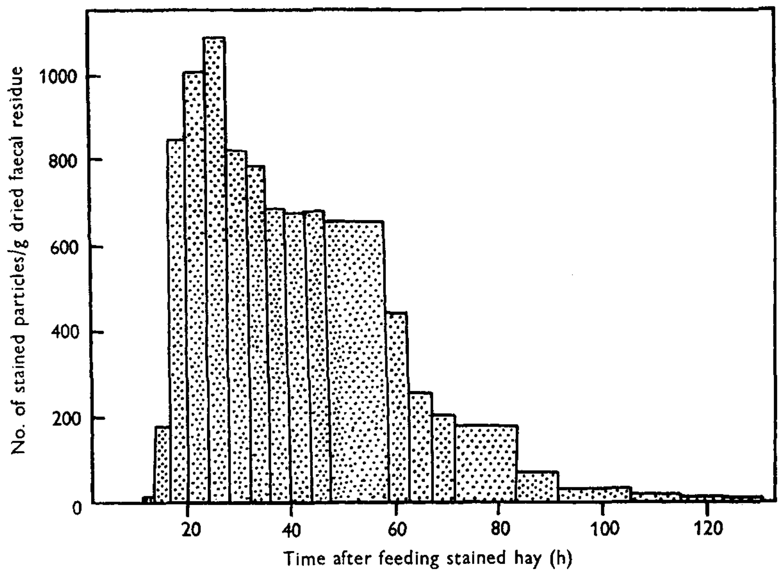

Fig. 3. Concentration of coloured particles in the faeces of an adult goat after the feeding of a single meal of stained hay (goat no. 4, Exp. *A*).

decided to use for comparative purposes the times of 5 and 95% excretion instead of the times of first and last appearance, as these values are easier to measure with accuracy.

The times of 5% excretion (Table 1) were fairly constant throughout, and only varied between 13·5 and 18·0 h (mean 16·1 ± 1·3 h). There was no obvious tendency for this time of 5% excretion to be a characteristic of the individual animal, because differences between consecutive experiments on the same goats were nearly as great as between different goats. The time of 95% excretion (Table 1) ranged from 60·0 to 87·0 h (mean 74·7 ± 8·1 h) and, in contrast to the 5% excretion time, was fairly constant for each goat. For example, in goat no. 1 the times were 65·0 and 64·0 h, in goat no. 5, 84·0 and 87·0 h and in goat no. 7, 78·0 and 78·0 h.

These findings suggest that, although in all the goats excretion of the stained marker began (5% excretion time) at about the same time, its final excretion (95% excretion time) showed a tendency to be a characteristic of each individual animal.

Body-weight

As there was such a wide difference in weight between the eight goats, the possibility of a relationship between this factor and rate of passage was investigated. It can be seen from Table 1 that the heaviest goat (no. 8) weighed more than twice as much as the lightest goat (no. 5) and yet there was little difference between the R values obtained for these two goats. In contrast, goats nos. 2 and 5, which were of similar body-weight, showed a great difference in R value. The correlation coefficient (r) calculated from the R values and body-weights of the goats confirmed that there was no significant relationship between the two factors. Similarly, there was no correlation between the weights of the goats and the times of 5 and 95% excretion of marker.

Food intake

The daily food intake (g dry matter/kg body-weight) of the same goats on consecutive experiments was fairly constant and was sufficient to maintain body-weight. The food intake of different goats, however, varied between 22·6 and 35·2 g/kg body-weight (Table 1). In general the smaller goats consumed more food per kg body-weight than the larger ones, but this was to be expected since basal metabolism and food requirement are proportional to surface area and not to body-weight. To enable more exact comparisons to be made between goats of varying weights, food intake was expressed as g dry matter/(kg body-weight)$^{\frac{2}{3}}$ (Brody, 1945). The differences between animals were then somewhat reduced, although goats nos. 1–3 still showed higher values than the others (Table 1). These three goats also had low R values, which suggested that a fast rate of passage might be associated with a high food intake. This suggestion is supported by an analysis of covariance which shows that, although within animals there was no correlation between mean retention time and food intake, that between animals was $-0·763$, which is just statistically significant ($P \sim 0·05$).

Dry-matter content of faeces

Ewing & Smith (1917) suggested that in cattle the dry-matter content of the faeces could be used as a measure of the rate of excretion of the food, the moister the faeces the faster the rate. As considerable variations were encountered in the dry-matter content of the faeces in the different experiments (Table 1) this suggestion was investigated further, but no correlation was found between the mean dry-matter content and either the R value or the 95% excretion time. For example, goat no. 2, which had the lowest R value, had about the same dry-matter content as goat no. 4 which had the highest R value (Table 1).

A statistically significant relationship ($r = +0·51$, $P = <0·05$) was found between dry-matter content of faeces and time of 5% excretion. If, as Balch (1950) suggested, the time of 5% excretion represents the rate of passage of food through the portion of the alimentary tract posterior to the reticulo-rumen (omasum, abomasum and intestine), then the water content of the faeces may indicate the rate of passage of food residue through this part of the tract. It is, however, unlikely that the rate of passage is the only factor governing the dry-matter content of the faeces.

DISCUSSION

The results of these experiments suggest that the rate of passage of foodstuffs in the adult goat, as measured by using stained hay as a marker, follows a fairly constant pattern. The excretion curves were all of the same general shape, although some goats excreted the marker more rapidly than others.

Expressing the results in terms of the *R* value (mean retention time in h) proved to be a convenient method for comparing different excretion curves. Variations between the *R* values in the experiments on eight goats were small (coefficient of variation 9·5 %).

The marker always first appeared in the faeces between 11 and 15 h after feeding, which agrees closely with the findings of other workers who used goats. Columbus (1936), for example, first found the stained marker after 13–15 h, and Biondo (1953) after 12–16½ h. In contrast, Balch (1950) found that the first appearance of the marker in cattle occurred over a range as wide as 12–24 h.

The stained hay finally disappeared from the faeces 6–7 days after feeding, which is a considerably shorter period than those found by Columbus (1936) and Biondo (1953) which were 17–19 and 11–17 days respectively. The whole pattern of excretion in the present experiments was found to be much more rapid, and one possible explanation is that the stained straw and oats used by Columbus and Biondo might be excreted at a different rate from stained hay. This suggestion is supported by the fact that in four of my experiments in which stained rye straw, as used by Columbus, was fed at the same time as hay stained another colour, the straw was excreted more slowly. This difference could be due to longer retention of the straw because of its lower digestibility and the same explanation might apply to the oat husks used by Biondo. Another difference in technique was that Columbus and Biondo counted all the stained particles that they could detect. They would thus be able to count very small particles, which might be the only ones present during the final stages of the experiment, and which in my experiments would be washed through the gauze filter.

As the technique used in the present experiments was the same as that used by Balch (1950) with cattle, it was possible to compare the results for the two species. A comparison (Fig. 4) of a typical excretion curve for the goat with one plotted from the results obtained by Balch (1948) shows that the curves are of similar shape but that excretion is slightly more rapid in the goat. A measure of this difference in rate of passage can be made by comparing the rates of excretion of the marker between the times of 10 and 80 % excretion in the two species. In the goat an average of 2·1 %/h was excreted as compared with an average of 1·5 %/h in cattle (Balch, 1950).

Owing to wide differences in technique employed it is not possible to make any worth-while comparisons between the results obtained with the goats and those obtained by other workers in sheep. But Columbus (1936), who worked with both goats and sheep, found little difference between them.

Although the goats varied widely in body-weight there was no evidence that it was related to the *R* value. Some of the results suggested that a large food intake was associated with a rapid rate of passage, and analysis of covariance indicates that an animal which habitually ate more tended to have a lower mean retention time, but that when an individual animal ate more than usual, there was no tendency for its mean retention time to be decreased. Variations in the dry-matter content of the faeces were not accompanied by changes in R value, but there was a positive relationship ($P = < 0.05$) between the 5 % excretion time and the mean dry-matter content of the faeces over the entire experiment. The moister the faeces the earlier was the 5 % excretion time,

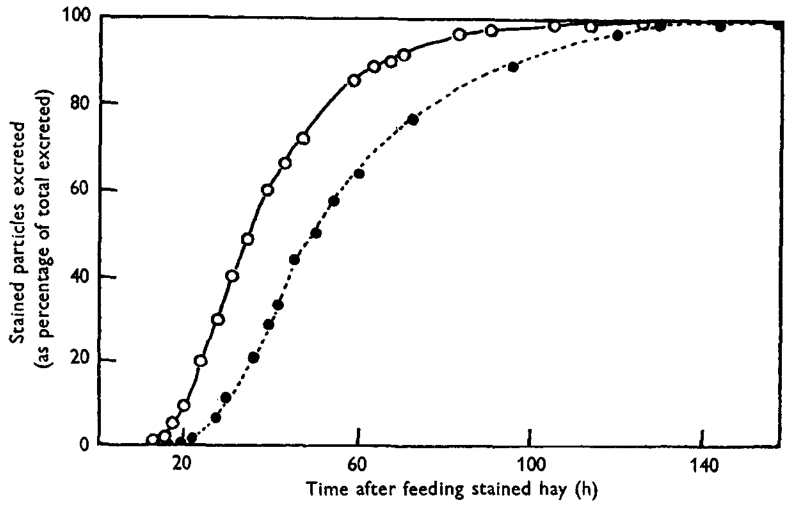

Fig. 4. Comparison of the rates of excretion of stained hay by goats and cattle. The curve for cattle was plotted from values of Balch (1948). ○—○, goats; ● - - -●, cattle.

which suggested that the dry-matter content of the faeces was mainly associated with the rate of passage through the intestines. The water content of the faeces might well be related to the time spent in the large intestine where most water absorption occurs.

Further work is planned to study the effects of changing or limiting the diet.

SUMMARY

1. Sixteen experiments to determine the rate of passage of foodstuffs were carried out on eight adult goats given hay *ad lib.* and calf nuts.

2. In each experiment the goat was given 10–20 g of stained hay, and the coloured particles were counted in samples of faeces collected at different intervals.

3. A value 'R', representing the mean retention time in hours of the stained hay, was calculated from percentage excretion curves, and was used as a measure of rate of passage.

4. Stained particles first appeared in the faeces after 11–15 h, reached a maximum at about 30 h and disappeared after 6–7 days. The R values ranged from 32·2 to 44·8 h (mean $38{\cdot}0 \pm 3{\cdot}6$), and varied more widely from goat to goat than in individual animals.

5. Mean retention time bore no relationship to body-weight but was related to daily food intake measured as g dry matter/(kg body-weight)$^{\frac{3}{4}}$. The greater the food intake the lower was the R value.

6. A significant relationship was found between dry-matter content of faeces and time of 5% excretion of stained hay.

7. These results are compared with those found by other workers with goats and also with cattle.

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The effect of penicillin on the thiamine requirement of the rat

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Some antibiotics are reported to have a sparing effect on certain B-vitamins when these are deficient in the diet of rats (Lih & Baumann, 1951; Sauberlich, 1952; Schendel & Johnson, 1954*a*; Johnson, Schendel, Hartsook, Batchelor, Promislow & Cohn, 1953): various suggestions have been made as to the mechanism of this action. For example, penicillin may spare thiamine by (1) increasing its absorption from the diet, (2) preventing its bacterial destruction or utilization in the tract or (3) increasing its intestinal synthesis. In any event the net result would be to make more thiamine available to the animal. This increase in available thiamine has been demonstrated by analysing the carcasses and urine of rats on a suboptimal thiamine intake, with or without penicillin (Schendel & Johnson, 1954*a*). From this finding one might expect a decreased thiamine requirement in the presence of dietary penicillin. The purpose of the experiments reported here was to study this question.