Br. J. Nutr. (1973), 30, 361

The effect of bypassing the rumen with supplements of protein and energy on intake of concentrates by sheep

BY E. R. ØRSKOV, C. FRASER AND R. PIRIE
The Rowett Research Institute, Bucksburn, Aberdeen, AB2 9SB

(*Received* 27 *November* 1972 – *Accepted* 23 *February* 1973)

1. Two experiments were conducted with young early-weaned lambs to measure the voluntary intake of dry concentrates when additional protein or lactose was given as a fluid preparation from a bottle.

2. The voluntary intake of a barley–urea diet (130 g crude protein/kg) was increased by 10–15 % as a result of giving 2·3 g nitrogen/d as a fish-protein concentrate in fluid suspension. Amounts greater than 2·3 g N/d did not further increase voluntary intake but increased growth rate and food conversion ratio. Urea given as a solution in water in the same way in amounts equivalent to 4·6 N/d had no effect on voluntary intake.

3. The voluntary intake of a high-protein barley–fish-meal diet was decreased by giving 10 or 20 % of the estimated intake as lactose by bottle. The results indicated that maximum energy intake was achieved with the basal diet, since the decrease in energy intake was about equal to the amount given in the solution bypassing the rumen.

In recent years much effort has been directed towards elucidating the mechanisms regulating the voluntary intake of food by ruminants. With forage diets the voluntary intake is largely limited by physical distension of the forestomach, as recently discussed by Campling (1970). With concentrate diets, on the other hand, ruminants tend to adjust their intake to achieve a constant intake of digestible energy (Baumgardt, 1970). When the intake is regulated by physical distension, dry-matter intake increases with increasing digestibility, whereas the converse is true with concentrate diets. These are generalizations; the point, for instance, where one mechanism operates and another takes over is obviously not well defined and may be influenced by many factors such as animal species, particle size of the feed (Andrews, Kay & Ørskov, 1969) and the palatability of the diets (Greenhalgh & Reid, 1971).

Observations which cannot be satisfactorily explained by either mechanism are those of Egan (1965) and Egan & Moir (1965). They showed that infusion of casein into the duodenum increased the intake of a low-quality roughage diet by about 42 % whereas infusion of an isonitrogenous amount of urea increased intake by only about 12 %. These observations were interpreted to suggest that the protein status of the animal had an effect on voluntary intake, since the effect of urea could be explained by an increase in the recycling of urea to the rumen with a consequent improvement in the rate of rumen fermentation.

In lambs given diets consisting of barley and fish meal, it was shown (Ørskov, Fraser, McDonald & Corse, 1971) that voluntary intake increased when the protein concentration was increased from 11 to 15 % crude protein in the dry matter. It was difficult to explain this increase in intake. The effect could have been due either to changes in the rate of rumen fermentation or, according to Egan, to an improved protein status of the animal, for it had been shown by Ørskov, Fraser & McDonald (1971) that fish meal added to a barley diet increased the amount of protein absorbed from the small intestine.

The experiments reported here were initiated to investigate the effect on the voluntary intake of barley-based diets of giving protein or lactose in solution, by bottle, so that they bypassed the rumen (Ørskov & Benzie, 1969). A preliminary account of part of this work has been published (Ørskov, Fraser & Corse, 1971).

EXPERIMENTAL

Animals

Expt 1. Ten male and ten female Suffolk ♂ × North Country Cheviot ♀ lambs were used. They were weaned at 2–3 weeks of age and taught to drink milk from a bottle fitted with a teat. Dry concentrate food and water were offered *ad lib.* At about 15 kg live weight, when 6–7 weeks of age, they were allocated to the experimental treatments.

Expt 2. Ten male Finnish Landrace ♂ × Dorset Horn ♀ lambs and ten female Suffolk ♂ × (Finnish Landrace ♂ × Dorset Horn ♀) lambs were used. They were weaned and treated as for the lambs in Expt 1, and were allocated to the experimental treatments at a weight of between 11 and 15 kg.

Design and treatments

Expt 1. Two male and two female lambs were allocated at random to each of the five treatments shown below. All received, *ad lib.*, a basal barley concentrate diet that contained (per kg) 960 g rolled barley, 9 g urea, 15 g dicalcium phosphate, 15 g limestone, 150 mg $ZnSO_4.7H_2O$, 80 mg $MnSO_4.4H_2O$, 0·43 mg $CoSO_4.7H_2O$, 200 mg MgO, 1·5 mg retinyl palmitate, 0·025 mg cholecalciferol and 20 mg DL-α-tocopheryl acetate. The diet, which was pelleted through a 7·7 mm die, contained 130 g crude protein/kg dry matter. The lambs also received daily, by bottle, 500 ml water containing a supplementary N source. Three of the treatment groups received different amounts of a fish-protein concentrate (FPC: Astra Nutrition, A. B. Mölndal, Sweden) containing 900 g crude protein/kg dry matter, namely 17 g FPC (2·3 g N), 34 g FPC (4·6 g N) or 51 g FPC (6·9 g N). The fourth group received 10 g urea (4·6 g N) and the controls were given no supplement in the water. The lambs were given the basal concentrate once daily in amounts estimated to be about 10% in excess of voluntary intake. The uneaten feed was recorded three times weekly and dried to constant weight at 100°. The liquid supplement was divided into four equal 125 ml portions and given at 08.00, 12.00, 16.00 and 20.00 hours from a bottle fitted with a teat.

Expt 2. In an initial period of 2 weeks the lambs were given 400 ml cow's milk daily by bottle, and the voluntary intake of a basal, high-protein concentrate diet was measured. The basal diet consisted of (per kg) 840 g rolled barley, 145 g white-fish meal and 15 g limestone: it contained 198 g crude protein/kg dry matter. Apart from controls, the lambs were given supplements of lactose either in solution (by bottle) or as a solid incorporated into the barley – fish-meal diet.

Four lambs (two males and two females) were allocated at random to treatments as follows.

Feeding regimen

1 Barley – fish-meal diet given *ad lib.* (control)
2 Barley – fish-meal diet given *ad lib.* with an estimated 10 % of food intake as lactose by bottle
3 Barley – fish-meal diet given *ad lib.* with an estimated 20 % of food intake as lactose by bottle
4 Barley – fish-meal diet with 10 % lactose incorporated given *ad lib.*
5 Barley – fish-meal diet with 20 % lactose incorporated given *ad lib.*

All lambs received daily from a bottle approximately 300 ml water which contained the lactose when this was supplied in the liquid form. The amount of lactose to be given in the water by bottle was calculated by estimating the intake from the amount of concentrate consumed during the previous week and the times of feeding were the same as in Expt 1. The concentrate was offered in a way similar to that adopted in Expt 1. The all-solid diets contained: 100 g lactose and 900 g basal diet/kg; and 200 g lactose and 800 g basal diet/kg. The trace minerals and vitamins included were the same as for Expt 1 and all diets were pelleted through a 7·7 mm die.

For both experiments, fresh water was always freely available from a trough and the lambs were randomly allocated to individual pens and bedded with sawdust.

Slaughter procedure

When the lambs weighed about 45 kg (Expt 1) or 40 kg (Expt 2) they were taken to the slaughter-house where the cold carcass weight and the weight of the carcasses immersed in water at about 7° were recorded. For Expt 2, samples of rumen fluid were obtained immediately after slaughter. The proportions of volatile fatty acids were determined on acidified samples of rumen fluid by gas–liquid chromatography (Pye 104) with a flame ionization detector (Fell, Kay, Whitelaw & Boyne, 1968).

RESULTS

Experiment 1

The lambs were in good health throughout the experiment and drank eagerly from the bottle at feeding times.

Daily feed intakes at given times were calculated from the slopes of graphs of cumulative feed intake against time. The live weights corresponding to these times were read from graphs where live weight was plotted against time. There was no significant correlation between initial weight and voluntary intake at subsequent weights. The effect of the treatments on the daily intake of the basal feed is given in Table 1. At 25 kg live weight, treatment differences in voluntary intake were not statistically significant ($P < 0·1$). At 35 kg live weight, there was a rectilinear increase in voluntary intake with increasing amounts of supplementary protein ($P < 0·05$), the first increment having the greatest effect. At 45 kg live weight there was a curvilinear response to effects of protein supplementation ($P < 0·01$). Supplements of urea did not significantly improve intake of the basal diet at any live weight.

The effects of the treatment on growth rate and food utilization are given in Table 2.

Table 1. *Expt* 1. *Daily intake of basal feed at various live weights by lambs receiving no supplement or given urea or increments of fish-protein concentrate* (*FPC*) *in solution by bottle so that the rumen is bypassed*

(Each value is the mean of four animals)

Supplement (g/d)	Intake (g dry matter/d)		
	25 kg live wt	35 kg live wt	45 kg live wt
None	851	1078	1265
17 FPC	994	1190	1415
34 FPC	927	1196	1561
51 FPC	1003	1241	1416
10 urea	853	1062	1246
SE of treatment means	48	44	43

Table 2. *Expt* 1. *Effect of giving urea or supplements of fish-protein concentrate* (*FPC*) *in solution by bottle so that the rumen is bypassed on growth rate and food conversion ratio by lambs from* 15 *to* 45 *kg live weight*

(Each value is the mean of four animals)

Supplement (g/d)	Initial wt (kg)	Final wt (kg)	Growth wt (g/d)	Food conversion ratio* (kg dry matter:kg gain)	Killing-out percentage	Specific gravity of carcasses
None	14·3	45·1	230	4·29	49·8	1·048
17 FPC	14·7	45·5	300	3·50	50·6	1·049
34 FPC	15·8	45·7	326	3·22	47·3	1·051
51 FPC	13·6	45·1	332	3·03	48·2	1·055
10 urea	15·2	44·7	224	4·28	50·2	1·052
SE of treatment means	—	—	22	0·21	1·4	0·005

* Including supplements of FPC.

The growth rate increased rectilinearly ($P < 0·01$) and the food conversion ratio (kg food/kg gain) decreased rectilinearly ($P < 0·001$) with fish-protein supplementation. The first increment of protein had the greatest effect, but the quadratic component did not reach significance. There were no significant differences between the lambs given the unsupplemented diet and those given urea. The killing-out percentages were not significantly influenced by the treatments. There were no significant treatment effects on the specific gravities of the carcasses.

Experiment 2

All lambs completed the experiment in good health. Occasionally the lambs receiving 20% of their diet as lactose from the bottle showed signs of scouring which suggests that some of the lactose was fermented in the large intestine. In the statistical analysis, both the intake during the first 2 weeks and the initial weights were tested as

Table 3. *Expt* 2. *Effect of giving* 10 *or* 20% *lactose in the concentrate compared with giving* 10 *or* 20% *of the estimated food intake as lactose in solution by bottle so that the rumen is bypassed on the voluntary food intake of lambs at* 20, 30 *and* 40 *kg live weight*

(Each value is the mean of four animals)

Supplement	Concentrate intake (g dry matter/d)			Mean daily intake of dry matter (g/d)	
	20 kg live wt	30 kg live wt	40 kg live wt	Consumed	Including lactose given from bottle
None	713	1077	1317	936	936
10% of intake as lactose (from bottle)	680	950	1083	838	939
20% of intake as lactose (from bottle)	630	925	945	757	919
10% lactose (in concentrate)	780	935	1203	947	947
20% lactose (in concentrate)	740	1045	1128	868	868
SE of treatment means	47	24	60	50	50

Table 4. *Expt* 2. *Effect in lambs on food conversion ratio of incorporating* 10 *or* 20% *lactose in the concentrate compared with giving* 10 *or* 20% *of the estimated food intake as lactose in solution by bottle so that the rumen is bypassed*

(Each value is the mean of four animals)

Supplement	Initial wt (kg)	Final wt (kg)	Growth rate (g/d)	Food conversion ratio (kg dry matter:kg live-wt gain)	Killing-out percentage	Specific gravity of carcasses
None	17·1	41·2	313	3·14	46·6	1·050
10% of intake as lactose (from bottle)	15·1	40·5	325	2·95	49·0	1·053
20% of intake as lactose (from bottle)	13·5	40·1	269	3·36	49·6	1·050
10% lactose (in concentrate)	14·8	40·2	292	3·36	49·6	1·048
20% lactose (in concentrate)	15·5	40·1	260	3·36	49·5	1·044
SE of treatment means			18	0·16	1·0	0·004

covariates, but no significant reduction in the residual standard deviations was achieved. The effects of treatment on intake are given in Table 3. At 20 kg live weight, the differences between treatments in the voluntary food intake were not significant; however, both at 30 and at 40 kg live weight, the voluntary intake decreased rectilinearly ($P < 0{\cdot}001$) with the percentage of the diet given as lactose by bottle. Lactose included in the dry food did not cause significant reductions in intake except at 40 kg live weight when intake was reduced on the diet containing 20% lactose ($P < 0{\cdot}05$), and at 30 kg when the diet contained 10% lactose. The general mean intake decreased rectilinearly ($P < 0{\cdot}01$) with percentage of the diet given as lactose from the bottle and there was no significant effect when lactose was included in the dry food. If the weight of the lactose which had been given from the bottle was added to the intake of concentrate there was no longer any significant effect of treatment.

The initial and final live weights of the lambs and food conversion ratio are given in Table 4. There were no significant effects of the treatments on either growth rate, food conversion ratio, killing-out percentage or the specific gravity of the carcass. The proportion of the volatile fatty acids in the rumen did not alter significantly with treatment. The mean molar proportions (%) were acetic acid 50·1, propionic acid 29·6, isobutyric acid 1·8, butyric acid 13·1, isovaleric acid 2·0, valeric acid 2·3, and caproic acid 1·1.

DISCUSSION

Effect of protein supplementation on the voluntary intake

The results of Expt 1 showed that when a basal diet was given which contained 130 g crude protein/kg, an amount which supplies sufficient nitrogen for the microbial fermentation of barley diets (Ørskov, Fraser & McDonald, 1972), food intake was increased when protein was given in such a way that it bypassed the rumen. This increase in intake is unlikely to have been due to an increased recycling of N through blood and saliva to the rumen since urea given by bottle had no effect, and it must be concluded that the effect noted was due to an improved protein status of the animal. It seems, therefore, that the increase in intake observed when fish meal was included in a similar diet (Ørskov, Fraser, McDonald & Corse, 1971), as referred to earlier, was due to an improved protein status of the animals as well, since part of the fish meal has been found to escape degradation in the rumen (Ørskov, Fraser & McDonald, 1971). This work thus confirms recent observations by Weston (1971) who found an increased intake when formaldehyde-treated casein was added to a lucerne diet.

The experiment does not however give information on the causal mechanisms, but the additional protein probably enables the animal to metabolize nutrients at a greater rate. It is not known whether a similar effect could be produced in animals whose protein requirement was equal to or lower than the amount of microbial protein produced by the fermentation of the basal feed.

The effect noted has points of similarity with the original observations of Egan (1965) and Egan & Moir (1965) who found an increase in the voluntary intake of a low-protein roughage diet when casein was infused through the duodenum. These Australian workers, however, used a low-protein roughage diet, whereas the concentrate diet used here contained 130 g protein/kg so that the experiments differed in both the protein content and the digestibility of the diets. Secondly, the animals used by Egan were mature, which means that their requirements for protein would be very low. In the present work the lambs were consuming food at between two and three times their maintenance level and they were 2–4 months old.

Effect of protein supplementation on food utilization

The effect of protein supplementation on intake was mainly confined to the lowest increment of supplementation after which there was little or no further increase. There were, however, further small effects on growth rate and conversion of food which were not significant.

The effect on intake of giving lactose in solution

The protein content of the high-protein barley diet used in Expt 2 was estimated from previous experience to give maximum intake even when 10 or 20% lactose was included in the diet. The reduction in intake observed when lactose was given so that the rumen was bypassed clearly indicates that about the maximum intake was achieved on the basal diet. The reduction in intake of basal feed was about equal to the amount supplied through the rumen bypass, consequently there appears to be little benefit in supplementing in this way so far as intake is concerned when basal feeds are given which do not impose physical limitation on intake. The effect of supplementation in this way when roughages are given is at present being investigated.

The net utilization of the lactose given in solution may be expected to be superior to that of the lactose consumed with concentrate since losses due to fermentation in the rumen are avoided. With the 20% level of substitution the capacity for digestion in the small intestine might have been exceeded since the consistency of the faeces was sometimes affected in a way that suggested excess fermentation in the large intestine (Ørskov, Fraser, Mason & Mann, 1970).

The authors thank Mr I. McDonald for the statistical analysis of the results, Mr J. C. Gill and the Metabolic Staff for the care of the experimental animals and Mr R. S. Reid for the volatile fatty-acid analysis.

REFERENCES

Andrews, R. P., Kay, M. & Ørskov, E. R. (1969). *Anim. Prod.* **11**, 173.
Baumgardt, B. R. (1970). In *Physiology of Digestion and Metabolism in the Ruminant* p. 235 [A. T. Phillipson, editor]. Newcastle upon Tyne: Oriel Press.
Campling, R. C. (1970). In *Physiology of Digestion and Metabolism in the Ruminant* p. 226 [A. T. Phillipson, editor]. Newcastle upon Tyne: Oriel Press.
Egan, A. R. (1965). *Aust J. agric. Res.* **16**, 451.
Egan, A. R. & Moir, R. J. (1965). *Aust J. agric. Res.* **16**, 437.
Fell, B. F., Kay, M., Whitelaw, F. G. & Boyne, R. (1968). *Res. vet. Sci.* **9**, 458.
Greenhalgh, J. F. D. & Reid, G. W. (1971). *Br. J. Nutr.* **26**, 107.
Ørskov, E. R. & Benzie, D. (1969). *Br. J. Nutr.* **23**, 415.
Ørskov, E. R., Fraser, C. & Corse, E. L. (1971). *Proc. Nutr. Soc.* **30**, 25A.
Ørskov, E. R., Fraser, C., Mason, V. C. & Mann, S. O. (1970). *Br. J. Nutr.* **24**, 671.
Ørskov, E. R., Fraser, C. & McDonald, I. (1971). *Br. J. Nutr.* **25**, 243.
Ørskov, E. R., Fraser, C. & McDonald, I. (1972). *Br. J. Nutr.* **27**, 491.
Ørskov, E. R., Fraser, C., McDonald, I. & Corse, E. L. (1971). *J. agric. Sci., Camb.* **77**, 351.
Weston, R. H. (1971). *Aust. J. agric. Res.* **22**, 307.

Printed in Great Britain