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The protection of dietary components from rumen fermentations

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Exposure of food to the bacteria and protozoa of the rumen has both advantages and disadvantages; it enhances the nutritional value of poor foods but may detract from the value of highly nutritious foods that could be digested without the aid of the micro-population of the rumen. This state of affairs has clear benefits for free-living ruminants as it assists them to survive during winter or during the harsh, dry conditions of warm climates. The extravagant use of foods when plenty is available probably does not matter very much to wild ruminants. It does however matter to the farmer who has to grow or buy food for his beasts. It is for this reason that considerable attention has been given recently to the protection of food constituents from the effects of the rumen. The first method is to make use of the oesophageal groove mechanism of young animals to convey liquid foods direct to the abomasum and the second is to process dietary additives with the object of increasing their resistance to the processes that go on in the rumen.

The oesophageal groove mechanism

The fact that milk bypassed the reticulum and rumen in the young calf was noted by early authors who attributed this to the oesophageal groove. The experiments of Wester (1930) established that closure of the groove and the passage of milk or other fluids to the rumen was a reflex involving excitatory areas in the mouth or pharynx. Since atropine inhibited closure of the groove, he contended that vagal efferent fibres were involved. Later, Comline & Titchen (1951) established that stimulation of the superior laryngeal nerve of calves caused reflex closure of the groove and that efferents were confined largely to the dorsal abdominal root of the vagus—an observation also made by Duncan (1953) with conscious lambs. Inhibition of the reflex was induced by central stimulation of the vagal branch to the abomasum and also by stimulation of the peripheral end of the splanchnic nerve. More recent work by Newhook & Titchen (1969) provides evidence that although the abdominal roots of the vagi include the efferent fibres concerned with closure of the groove, not all are atropine-sensitive and the efferent arm of the reflex appears to be more complicated than the earlier evidence suggests.

Watson (1941) and Watson & Jarrett (1944) made a detailed study of the behavioural patterns of lambs in relation to drinking or sucking milk or water from nipples. They found that the behavioural pattern of the animal is closely connected to the efficiency with which the oesophageal groove mechanism conveys fluid to the abomasum. Fluids passed to the abomasum of lambs that sucked or drank eagerly with the pleasure pattern they normally show when sucking the ewe irrespective of whether milk or water was given and irrespective of whether they sucked or drank. This response declined with age. Wise & Anderson (1939) obtained similar results with calves although drinking produced a slower response from the groove than sucking and was not always effective. These studies can be summarized by saying that the reflex that excites the oesophageal groove mechanism can be conditioned. It also implies that the phenomena of reinforcement and inhibition are important as for other conditioned reflexes. The use of the oesophageal groove mechanism to convey milk or other fluid foods to the abomasum under farming conditions will depend upon how efficiently the stockman can condition the reflex to feeding from an artificial teat or drinking from a trough, and how far he can maintain such conditioning and eliminate inhibitory influences. It has been practised for generations with calves and there is no reason why it should not be common practice with lambs if this kind of husbandry has a place in farming practice.

It is common knowledge to all of us who have reared lambs on a bottle that some lambs are more easily trained than others, that some will retain their delight in sucking from a bottle for longer than others, and that a few lambs never apparently become accustomed to this substitute for mother. One of Watson's (1941) sheep retained its interest in sucking from a teat for 4 years with consequent closure of the oesophageal groove mechanism.

Ørskov, Benzie & Kay (1969) were able to train lambs to suck from a bottle 2 weeks after they were weaned from the ewe. They were also taught to drink milk from a trough. Under both circumstances closure of the groove was observed when barium suspension was injected into the oesophagus through a catheter so bypassing the afferent receptors of the reflex: therefore, stimulation of the groove can only have been due to stimulation of higher centres. Their study emphasizes the fact that the oesophageal groove mechanism can be successfully conditioned in lambs and that when trained animals are excited or teased by the prospect of a liquid feed, either from a bottle or a trough, closure of the groove often occurs even before feeding starts. The predictability of this event depended on the circumstances. They also mention some differences between lambs in the speed with which they learnt whether or not a milk meal would follow teasing.

Ørskov & Fraser (1969) used this technique to compare protein supplements for lambs given either in a dry state to a basic barley diet or as a liquid from a teat. Nitrogen retention was improved by liquid feeding and urinary nitrogen was substantially less although faecal excretion was greater for the liquid-fed animals compared to the lambs receiving a dry-protein supplement.

A later experiment (Ørskov, Fraser & Corse, 1970) in which casein, white fish meal or soya-bean meal were given as dry supplements or in liquid suspension to trained lambs confirmed this result and greater weight increases occurred in the liquid than the dry-fed lambs.

It appears to be a common experience that in groups of lambs fed in this way that a few animals do not respond as expected. There may be many reasons for this but it is unlikely that it is due to a physiological defect in the mechanism of the reflex as has been suggested. Failure to condition the reflex adequately in individual animals, which for one reason or another are more refractory to training, is a more probable cause if no pathological reason can be found. The method seems to need considerable expertise in animal management and this the workers at the Rowett Institute possess.

The processing of dietary constituents

The losses that occur as a result of the activity of the micro-population of the rumen are due to the exothermic heat of fermentation, to the production of methane, to the absorption of ammonia derived from protein and other simple nitrogenous materials, and to conversion of starches and sugars to volatile fatty acids. It may be argued that the hydrogenation of long-chain fatty acids is undesirable but this does not constitute a loss in the sense used here. Most attention has been given to the protection of proteins.

Chalmers, Cuthbertson & Synge (1954) showed that if casein was subjected to heat treatment and compressed into small lumps it could then pass from the rumen to the abomasum intact. The initial demonstration was purely qualitative but this observation has led to much work comparing protein supplements that were or were not subjected to heat treatment. Thus heat-treated casein can improve nitrogen retention when the nitrogen balance of the animal is close to zero.

Much work has been done in studying the influence of the solubility of proteins in relation to ammonia concentrations in the rumen, and to its relation to growth, lactation and nitrogen balance. This subject is reviewed by Chalmers (1961).

Recently, interest has centred on the treatment of casein with formalin as a means of reducing its susceptibility to degradation in the rumen.

Reis & Schinckel (1963) stimulated wool growth by infusing cysteine or methionine into the abomasum of sheep, but corresponding quantities of casein by mouth did not. In this they confirm the earlier work of Marston (1935) on the effect of sulphur-containing amino acids. The use of formalised casein by mouth was examined by Ferguson, Hemsley & Reis (1967) who noted a marked stimulating effect on wool growth from the addition of casein treated in this way when compared to untreated casein as a dietary supplement. Later, Reis & Tunks (1969) showed that formalised casein by mouth produced the same effect on wool growth as untreated casein given by abomasal infusion. In all those experiments some depression in the apparent digestibility of treated casein was noted.

A careful study by MacRae, Ulyatt, Pearce & Hendtlass (1972) using sheep with a bypass in the duodenum and ileum does much to clarify this situation. The sheep were maintained on a basic diet of dried grass having a high content of hot-water-soluble carbohydrate amounting to 22·3% and a nitrogen content of 2·6% of the dry matter. They added to this diet either 60 g of formalised casein or 60 g of untreated casein and studied the nitrogen fractions eaten, passing to the duodenum, passing to the caecum and excreted in the faeces in terms of ammonia-nitrogen, non-

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ammonia nitrogen and of sixteen amino acids, excluding cystine and tryptophan. They found that both treated and untreated casein caused an increase in amino acid passing to the duodenum although it was greater for the treated casein than for the untreated casein. Their results suggest that the treated and untreated casein provided some 37 and 18 g respectively of additional amino acid passing to the intestine and of these some 21 and 5 g disappeared in the small intestine. Sheep receiving the treated casein lost rather more amino acid in the large gut than those receiving untreated casein when compared to control animals receiving no casein.

This experiment provides some quantitative results from which to assess the extent of the benefit derived by sheep from formalised casein in terms of amino acids. It might be that the difference between treated and untreated casein would be accentuated in diets containing little or no soluble carbohydrate.

There has been little work done on fodder proteins and only two accounts are available. Hemsley, Hogan & Weston (1970) treated a clover-rich pasture fodder with a 10% (w/v) formaldehyde solution by spraying which gave a rate of 1 g formaldehyde per 100 g dry forage. This was bagged in plastic bags for 5 d and dried in an air-stream at 40° for 2 d. Formaldehyde treatment depressed organic-matter digestibility by about 2% and the apparent digestibility of total nitrogen by about 1 g/d. They calculated from the estimated rate of flow to the intestine that nitrogen disappearing in the intestine was greater for the treated forage than for the untreated forage. The general conclusions are supported by the observations that the concentrations of ammonia in the rumen of sheep eating the untreated forage were greater than for those eating the treated forage.

Faichney & Lloyd-Davies (1972) treated goundnut meal with formaldehyde and used it to supplement the diet of calves otherwise given a barley-rich diet to give protein contents of 13 and 20%. At the high rate of supplementation, animals receiving the treated meal increased weight at the same rate as calves receiving the untreated meal. At the lower level of supplementation the calves receiving the treated meal had a slight but statistically non-significant advantage in live-weight gain.

Whether formaldehyde treatment of fodders and protein-rich cakes comes into general use remains to be seen. The available information suggests that from a production point of view it is likely to be of most use in terms of wool growth.

It is necessary here to mention that Leroy, Zelter & Francois (1964) observed that treating soya-bean meal and arachis cake with a vegetable tannin protected the protein of these foods when incubated with rumen liquor in an artificial rumen. Cellulose fermentation was not impaired and subsequently the protein present was digestible by pepsin and trypsin. There seem to have been few if any feeding trials to see whether this method is useful in vivo although Oslage & Becker (1958), when testing the digestibility of the carob bean, which has a high tannic acid content, observed not only that in sheep it was most indigestible but that its presence depressed the digestibility of the remainder of the diet.

The protection of lipids. Formaldehyde-treated casein has been put to another use by Scott, Cook & Mills (1971). These workers have made emulsions of vegetable oils and casein which were spray-dried with a similar technique to that used to dry-milk powder or butter. This process produces small droplets of oil embedded in a casein shell. These particles are then treated with formaldehyde either by spraying or by previously introducing formaldehyde with the oil:protein emulsion. The particles measured from 10–60 μ in diameter and the oil droplets embedded in the casein layer 0·1–4·0 μ in diameter. The amounts of formaldehyde added were varied from 0 to 4·8% by weight of casein giving, after drying, 0–2·1% formaldehyde by weight of casein. These particles, incubated in rumen liquor, protected the linoleic acid present from hydrogenation at the highest formaldehyde concentration but a concentration of 1·4% gave about an 80% protection.

These workers experimented with particles containing safflower-seed oil, sunflower-seed oil and linseed oil; the two former being rich in linoleic and the latter in linolenic acid. In brief, they have shown that when 500 g of particles are given daily in the diet of goats the composition of the milk fat is altered towards the composition of the oil administered. This has also occurred in cows and these effects occur within 24–48 h after administration. In sheep, depot fats are altered in the direction of the oil given. Clearly, the formaldehyde-treated casein protected the vegetable oils from hydrolysis in the rumen and hydrogenation of the acids so released. An experiment using ^{14}C-labelled linolenic acid in treated particles introduced into the abomasum showed that 30–40% of the label appeared in the milk fat and only about 1% appeared in the faeces. A more detailed investigation has confirmed the fact that the fatty acids of vegetable oils so given are largely absorbed from the intestine.

Conclusions

In parenthesis we may conclude that preparations designed to protect proteins from degradation in the rumen have a useful experimental purpose and may assist in defining more closely than before the requirements for essential amino acids for different physiological states of the animal. The protection of oils from the effects of the rumen may be a useful way of conveying a high-energy material past the rumen for in this organ its liberation may have a depressing effect generally on the metabolism of bacteria which seems to be the result of a physical effect. The possibility of deleterious effects of unusual quantities of unsaturated fatty acids on the metabolism of the animal should not be overlooked although ways of combating these effects can be adopted. It remains to be seen whether these methods and practices will find a place in commercial husbandry.

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