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SYMPOSIUM ON 'EFFECTS OF FOOD PROCESSING ON NUTRITION OF FARM ANIMALS'

The influence of physical processing on the intake, digestion and utilization of dried herbage

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The effects of physical processing of forage diets on their value as feedstuffs for ruminants has been reviewed by Minson (1963), Beardsley (1964), Moore (1964), Campling & Milne (1972), Greenhalgh & Wainman (1972), Jarrige, Demarquilly, Journet & Beranger (1973) and Wilkins (1973). In this review we have therefore attempted to concentrate attention upon the chemical and physical changes produced in forages by harvesting and processing, to indicate briefly the effects upon voluntary intake and the net energy (NE) of the feedstuffs, and finally to review the mechanisms which might explain the effects of processing.

Chemical and physical changes induced by harvesting and processing forages

At the high temperatures achieved normally during hot-air drying and sometimes during milling and packaging, non-enzymic browning occurs mainly as the result of the formation of enzyme-resistant linkages between the carbonyl groups of reducing sugars and amino groups of the protein fraction. The chemistry of these Maillard reactions has been reviewed by Hodge (1953) and Bjarnason & Carpenter (1969, 1970) and they conclude that lysine is the amino acid most susceptible to the formation of such linkages. A major consequence of these reactions is a reduction of the solubility of the protein. The oven-drying of a grass reduces the solubility of protein when compared with the fresh material and gives rise to increases in both the dietary protein escaping degradation (49%) and the microbial protein synthesized in the rumen (57%). The net result of these changes is to increase the total protein entering and absorbed from the small intestine by 51 and 73% (Beever, Cammell & Wallace, 1974). Increasing amino acid absorption in response to decreasing solubility of the protein in forages has been demonstrated by MacRae & Ullyatt (1974) and Beever, Thomson & Cammell (1976) and in commercial drying is attributed by Israelsen (1973) mainly to overdrying (product moisture less than 20%).

Pyrolysis may occur when driers are operated at or near capacity and also as a result of dry grinding and packaging. Wainman & Blaxter (1972), assuming no loss of ash, found that grinding and pelleting led to a loss of 8.6% of the organic matter in the original material and a corresponding increase in the protein content, indicating an 11% loss of carbohydrate. Long forages lose leaf during storage and handling, leaving residues having lower ash and protein contents, so it must be assumed that these estimates of loss by pyrolysis are maxima.

Since Minson's (1963) review, there have been several attempts to describe the effects of milling more precisely (Demarquilly & Journet, 1967; Hughes, 1967; Tetlow, 1974). However, methods of preparation and sieving and the expression of the results as a mean particle size or modulus of fineness (MF) of the meal have varied. There can be no precise equivalence between these two indices and the relationship must be curvilinear. For comparative purposes the mean particle size equivalent to MF of 3.0, 2.5, 2.0, 1.5, 1.0 and 0.5 are assumed to be 1.22, 0.90, 0.67, 0.48, 0.32 and 0.18 mm, on the basis of calculations made on several sieve analyses. The effect of grinding is to reduce particle size, increase the surface area and to increase the bulk density of both the leaf and stem fractions of forages (Laredo & Minson, 1975). The energy cost of grinding a dried Coastal Bermuda grass (*Cynodon dactylon* L.) increased from 48.2 to 237 MJ/t as the diameter of the holes in the screen was reduced from 6.35 to 1.59 mm, reducing MF from 2.95 to 1.99 and increasing bulk density from 75 to 237 kg/m³ (Butler & Hellwig, 1973). Troelson & Bigsby (1964) and Chenost (1966) used standardized wet-maceration and dry-grinding procedures to demonstrate the increase in the resistance of forages to comminution with advancing maturity. As the digestible organic matter of Italian ryegrass (*Lolium italicum* R.Br.) declined from 707 to 587 g/kg dry matter (DM) during primary growth, the energy required to pass 5 g through a screen with 1 mm diameter apertures increased by a factor of 2.31 from 0.381 to 0.882 Wh (270 to 635 MJ/t). The energy expended in grinding samples of 59 D-value in the same machine was much greater for primary-growth timothy (*Phleum pratense* L.) than primary-growth Italian ryegrass and much less for a leafy regrowth of timothy: 1.203, 0.882 and 0.743 Wh (R. J. K. Walters, personal communication). These differences would seem to be associated mainly with the leafiness of the crop, which is not always highly correlated with cell wall content (Cammell & Osbourn, 1972; Thornton & Minson, 1973). While the energy cost of fine grinding of mature forages can amount to 300 MJ/t or about 4% of the metabolizable energy (ME), the energy used in packaging is of the order of 150 MJ/t or 2% of the ME (Shepperson, Marchant, Wilkins & Raymond, 1972).

The effects of processing on the voluntary intake of forages by ruminants

Jarrige *et al.* (1973), using short-term trials with mature sheep, have shown that the intake of dried, mature herbage is increased as particle size decreases to a mean of 0.75 mm (MF 2.17) for lucerne (*Medicago sativa* L.) and 0.55 (MF 1.7) and 0.40 mm (MF 1.3) for ryegrass and tall fescue (*Festuca* sp.). Similar results were obtained with processed hays in earlier studies (Demarquilly & Journet, 1967).

Sheep given immature ryegrass and tall fescue of high digestibility increased intake in response to grinding and pelleting only as the MF was reduced to 1.09 (mean particle size 0.35 mm) and 0.84 (mean particle size 0.28 mm) (Tetlow & Wilkins, 1974). Further reductions in particle size did not increase intake and when the pellets were unstable and the diet dusty there was no significant increase in intake in response to reducing MF from 3.20 to 0.99 (Wilkins, Lonsdale, Tetlow & Forrest, 1972).

The increase in consumption in response to grinding and pelleting was shown to be greater (45%) in sheep than in cattle (11%) and greater in young animals (38%) than older animals (18%) of both species, and greater for mature than for immature herbage (Greenhalgh & Reid, 1973). The effect of pelleting on intake is much greater in short-term than in long-term experiments (Greenhalgh & Wainman, 1972; Greenhalgh & Reid, 1974).

Processing dried grass improves its usefulness as a supplement to long forage diets, particularly silages. Tayler (1970) demonstrated first with young beef cattle and later with lactating dairy cows (Tayler & Aston, 1973) that the milled and pelleted product of highly digestible grasses did not depress the intake of silage to the same extent as did normal concentrate supplements based on barley grains. These observations are supported by the work of McCullough (1972, 1974) and Gordon & McIlmoyle (1973).

It has been observed that when food intake is equal, reticulo-rumen fill is greater for chopped roughage, but at *ad lib.* intakes, when more of the pelleted diet is consumed, rumen fill is similar (Campling & Freer, 1966). Laredo & Minson (1975) showed a high positive correlation between intake and the rate of removal of organic matter from the reticulo-rumen for both chopped and ground and pelleted leaf and stem fractions. The reduction in particle size on pelleting leads to a more rapid passage of undigested material from the rumen and the differential response of cattle and sheep of various ages is probably related to the size of particles that can pass readily from the rumen, which in turn relates to the size of the animal (Greenhalgh & Reid, 1973). The rate of digestion of cell wall material in the rumen is often depressed by pelleting, particularly for grass diets (Campling & Freer, 1966) but can be enhanced on legume diets (Journet & Jarrige, 1967). The compact, square shape of food particles when lucerne is comminuted, relative to the elongated particles of grasses observed by Troelson & Campbell (1968), would seem to be a further means whereby digesta packs more densely in the rumen and passes more readily through the reticulo-omasal orifice and so accounts for the differences observed between grasses and legumes in their response to pelleting.

The effect of processing on the NE content of forages

When chopped or ground and pelleted grass herbage comprises the sole diet of sheep, the effect of processing is to increase the NE content of the forage. The magnitude of the response is negligible with highly digestible immature herbage and increases with declining digestibility or increasing maturity of the forage (Blaxter, 1973). These results, together with those of other authors who have

examined both grasses and legumes, are shown in Fig. 1, agreeing with Blaxter's (1973) observation and showing no real difference between grasses and legumes in their response to processing.

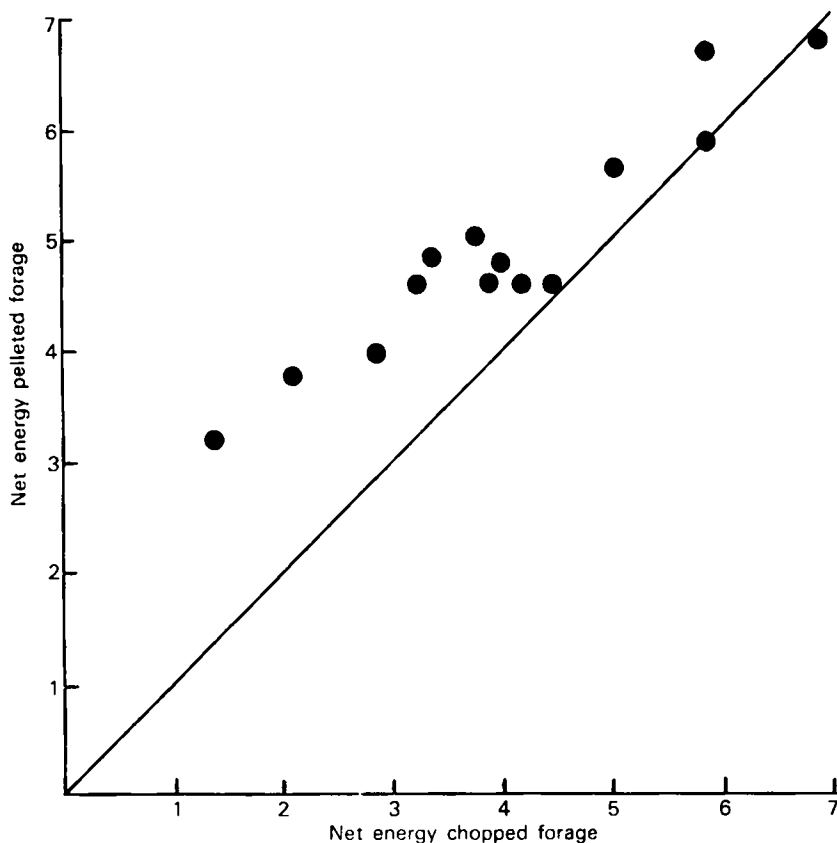


Fig. 1. The effect of processing on the net energy value of forages to sheep (MJ/kg dry matter). (From Forbes, Fries & Braman (1925), Blaxter & Graham (1956), Meyer, Gaskill, Stoewsand & Weir (1959), Paladines, Reid, Niekerk & Bensadoun (1964), Thomson & Cammell (1971), Wainman, Blaxter & Smith (1972), Blaxter (1973), Vermorel, Bouvier & Demarquilly (1974), Smith, Wainman & Dendy (1976) and Wainman & Smith (1976).)

When ground, pelleted forages are included in the diets of lactating cows together with some long forage and concentrates, the content of digested energy attributable to the forage pellets is depressed on average by 9% and methane losses are slightly reduced so that the effect of processing is to reduce the ME by 8%. However, the efficiency of use of ME for maintenance and milk and tissue production was improved by a similar proportion, so that the NE content of processed roughages in mixed diets can be equated with the NE content of the original long forage (Van Es & van der Honing, 1973).

The effect of processing on the losses of energy

The faecal output of energy by sheep consuming a processed grass diet increases as the fineness of grinding and the intake are increased, as a result of increased rate of passage out of the reticulo-rumen (Blaxter, Graham & Wainman, 1956). The increased faecal output is almost entirely accounted for by an increased output of cell walls in the faeces and the much greater effect upon grasses than upon legumes has been attributed to the high sugar content of the former depressing rumen pH and the rate of cell wall digestion in the rumen and the high buffering capacity of legumes resisting these changes (Osbourn, Terry, Outen & Cammell, 1974).

If processing depresses the energy digested and yet can increase the NE available for maintenance and production, it must also reduce the energy losses associated with eating and digestion or with the metabolism of absorbed nutrients. The time spent eating and ruminating by sheep and cattle increases as the fibre content in herbage increases and is reduced markedly by grinding and pelleting (Balch, 1969). Graham (1964) and Osuji, Gordon & Webster (1975) have estimated the cost of eating and ruminating on a dried, chopped herbage diet as 147 and 192 kJ/h, equivalent to 3.27 and 3.37 kJ/h per kg live weight (LW), and agree more closely in their estimates of the cost of eating as 2.26 and 2.20 kJ/h per kg LW. Osuji *et al.* (1975) found that when the same diets were ground and pelleted, the energy cost of eating and ruminating was reduced to 76 kJ/h or 1.33 kJ/h per kg LW. Webster, Osuji, White & Ingram (1975) found that the energy cost of eating these chopped and pelleted diets of lucerne and dried grass amounted to only 12 and 2 kJ/MJ gross energy (GE) and that the effect of pelleting in reducing energy loss was largely attributable to reduced losses at the level of tissue metabolism in the instance of the lucerne and in the aerobic metabolism of the gut and the body tissue for the grass diet. This, they concluded, implied the absorption of nutrients metabolized more efficiently as a result of processing. The metabolizability of the GE in the diets examined by these authors was high (0.55–0.62). Hogan, Weston & Lindsay (1969) examined chopped, dried diets of lower quality and, using the values derived by Graham (1964), calculated that the energy cost of eating accounted for 5–14% of the ME, and this alone could account for the decline in the efficiency of use of energy for fattening with advancing maturity.

Using sheep fitted with a rumen cannula and re-entrant cannulas at the proximal duodenum and terminal ileum, estimates can be made of the energy as volatile fatty acids (VFA) absorbed from the rumen, the energy and amino acids absorbed in the small intestine and the energy lost in the large intestine. Of the latter, 85% is assumed to be absorbed as VFA (Thomas & Clapperton, 1972). The sum of the energy absorbed at all three sites is hereafter termed the total absorbed energy (TAE). Estimates of this kind have been made on seven dried herbages, each in a chopped (C) and ground or pelleted (P) form. The herbages were: a lucerne, reported by Thomson, Beever, Coelho da Silva & Armstrong (1972) and Coelho da Silva, Seeley, Thomson, Beever & Armstrong (1972), two perennial ryegrasses (*Lolium perenne* L.) reported by Beever, Coelho da Silva, Prescott & Armstrong (1972) and Coelho da Silva, Seeley, Beever, Prescott & Armstrong (1972), a red

clover (*Trifolium pratense* L.) herbage, reported by Beever, Thomson & Harrison (1971), a cocksfoot (*Dactylis glomerata* L.) herbage, reported by Thomson & Beever (1972) and an Italian ryegrass and timothy herbage (Beever & Osbourn, unpublished results).

Grinding and pelleting increased the daily flow of cellulose, hemicellulose and energy into the small intestine on all these diets and the loss of these same constituents in the large intestine. The net result on the digestion of cell walls was nil on the legumes (C, 60%; P, 60%) but a significant decline in response to pelleting was seen on the grasses (C, 83%; P, 78%). In consequence of the reduction of carbohydrate fermented in the rumen the VFA produced in the rumen were reduced by processing from 5.77 to 4.62 mol/kg DM consumed. This resulted in less energy being absorbed as VFA on the pelleted diets, as illustrated in Fig. 2. While there have been many reports (Meyer, Kromann & Garrett, 1965; Cottyn & Boucque, 1971; Alwash & Thomas, 1972) of processing reducing the ratio, acetate: propionate in the VFA produced, in these studies the ratios were, for legumes, C 3.1, P 3.4, and for grasses, C 3.4, P 3.4.

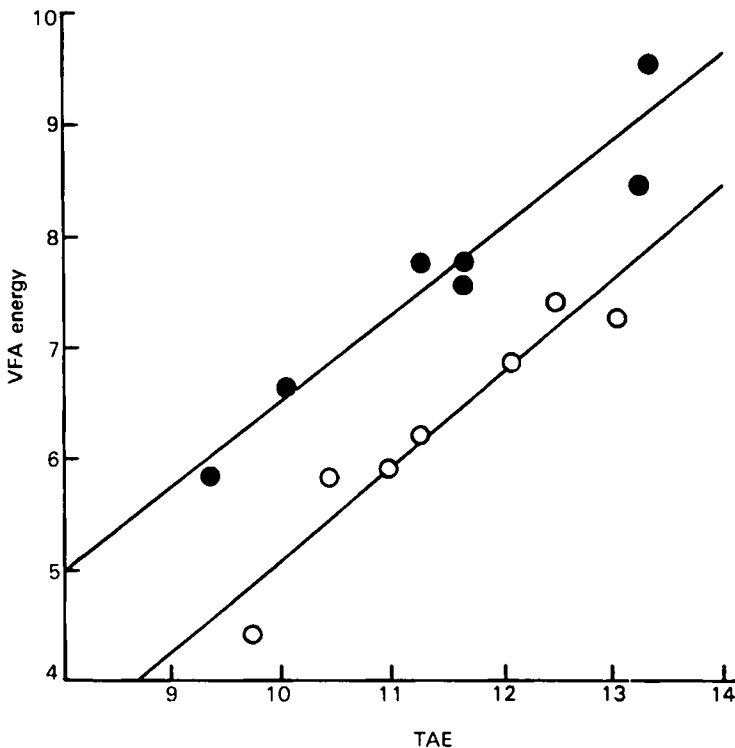


Fig. 2. Energy absorbed as volatile fatty acids (VFA) (MJ/kg dry matter (DM) intake) by sheep with changing concentration of total absorbed energy (TAE) (MJ/kg DM), for chopped (●) and ground and pelleted (○) forages. For chopped forages, VFA energy = $0.77\text{TAE} - 1.21$ ($r = 0.96$); for ground and pelleted forages, VFA energy = $0.84\text{TAE} - 3.30$ ($r = 0.96$).

Processing increased the flow of amino acids into the small intestine: the mean values observed were, as g amino acids/kg DM consumed, for the legumes, C 151, P 171, and for the grasses, C 136, P 144. The corresponding quantities of amino acids absorbed from the small intestine were 93, 106, 102 and 102 g/kg DM consumed. Beever & Osbourn (unpublished results) estimated that the microbial protein synthesized in the rumen per mol hexose equivalent fermented in the rumen was similar on chopped and pelleted diets and consequently pelleting reduced the flow of microbial protein into the small intestine. The dietary protein escaping degradation was increased by pelleting from 43 to 65 and from 26 to 57 g amino acids/d as the result of processing herbage of timothy and Italian ryegrass. Despite the implied changes in the proportions of dietary and microbial protein entering the small intestine, the mean composition of the amino acids absorbed was not significantly altered by processing although there was some suggestion of lower proportions of lysine, tyrosine and phenylalanine on the pelleted diets (Table 1).

Table 1. *The influence of the physical form of herbage consisting of timothy (Phleum pratense L.) and Italian ryegrass (Lolium italicum R.Br.) on the composition of the amino acid fraction absorbed from the small intestine of sheep (mg/g)*

Amino acid	Physical form		SEM
	Chopped	Pelleted	
Aspartic acid	65	68	0.66
Threonine	56	57	0.25
Serine	47	48	0.20
Glutamic acid	95	95	1.12
Proline	45	56	0.34
Glycine	66	61	0.18
Alanine	67	67	0.18
Valine	72	78	0.50
Methionine	29	26	0.17
Isoleucine	67	64	0.28
Leucine	103	104	0.42
Tyrosine	56	43	0.41
Phenylalanine	56	49	0.39
Lysine	77	70	0.32
Histidine	40	42	0.48
Arginine	53	71	0.51

Limited studies on the digestion of the lipid components of chopped and pelleted forages (Ross & Seeley, 1969; Outen, Beever & Osbourn, 1974; Outen, Beever, Thomson & Osbourn, 1975) have indicated that the total flow of long-chain fatty acids from the rumen is not influenced by processing, but Outen *et al.* (1975) showed that the ratio, unsaturated:saturated fatty acids in the fraction absorbed from the small intestine was significantly elevated due to pelleting (C 0.32, P 0.47).

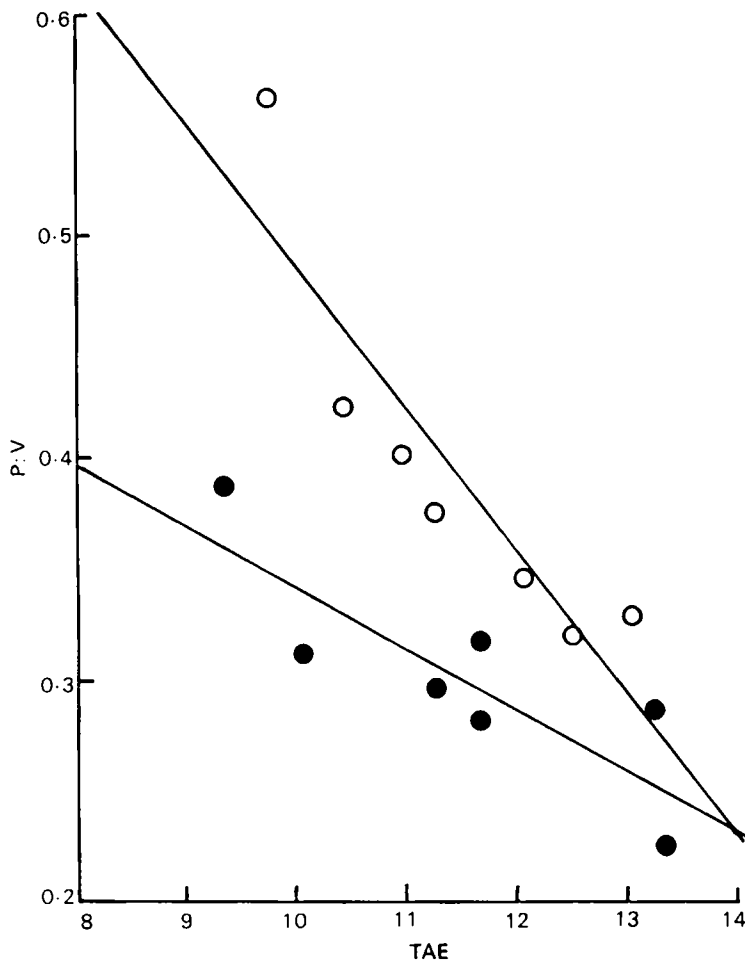


Fig. 3. Ratio, energy absorbed as protein:energy absorbed as volatile fatty acids (P:V) by sheep with changing concentration of total absorbed energy (TAE) (MJ/kg dry matter) for chopped (●) and ground and pelleted (○) forages. For chopped forages, $P:V=0.61-0.027TAE$ ($r -0.84$); for ground and pelleted forages, $P:V=1.12-0.063TAE$ ($r -0.90$).

Processing dried forages reduced the energy absorbed as VFA and increased the absorption of amino acids, particularly on the legume diets which were of low digestibility, without apparently affecting the composition of either fraction significantly. The combined effect of these changes is shown in Fig. 3, where the ratio, energy absorbed as protein:energy absorbed as VFA, is plotted *v.* TAE (MJ/kg DM). Protein is utilized for fattening with almost twice the efficiency of VFA (McDonald, Edwards & Greenhalgh, 1973). If these values are applied to the ratios shown in Fig. 3, the efficiency of use of absorbed nutrients on the chopped diets shows little change with decline in the concentration of TAE, as Hogan *et al.* (1969) concluded. Furthermore, at high TAE concentration the absorbed nutrients from chopped and pelleted diets would be utilized with equal efficiency, but as the concentration of TAE declines the higher ratio, protein energy:VFA energy

absorbed on the pellet diets would lead to the absorbed nutrients being utilized more efficiently on pelleted than on chopped diets.

While these observations provide some basis for concluding that processing alters the balance of nutrients absorbed and therefore the efficiency of utilization for fattening, nevertheless for mature forages the effect of processing on the energy cost of eating and possibly gut aerobic metabolism cannot be ignored.

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