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METABOLIC LIMITATIONS TO MILK PRODUCTION IN THE TROPICS

David S Parker

Department of Agricultural Biochemistry and Nutrition
University of Newcastle upon Tyne
Newcastle upon Tyne NE1 7RU, U.K.

[...]vironmental, nutritional and metabolic limitations to milk production in the tropics are described. Reduced feed intake is discussed in terms of animal response to high environmental temperature. The importance of adequate dietary protein levels, which probably reduce the heat increment of feeding, is emphasized. Experiments in which changes in rumen digestion were observed in heat stressed animals are described and the special problems of molasses feeding are discussed. Metabolic and endocrine responses in animals maintained in a tropical environment may be important limitations to milk production, however the lack of data in this area and the danger of extrapolating short term effects of heat stress to animals living in a tropical environment are emphasized. It is concluded that milk production provides an additional stress to animals in a hot environment and that yield may be improved by careful application of existing knowledge on the utilization and digestion of tropical feeds. Further work is required in the area of nutrition-endocrine interactions.

Key words: Milk production, tropics, metabolism

The level of production and the quality of milk produced by the dairy cow under tropical conditions is limited by a number of factors. Two of the more important of these are the reduction in voluntary feed intake by animals exposed to high environmental temperatures and the quality and type of feed available. In any consideration of these factors it is necessary to integrate data published from experiments carried out under tropical conditions with our knowledge of the biochemistry of nutrient utilization derived from experiments in more temperate areas of the world. It is important to bear in mind, however, that some data obtained from animals placed in hot environments for short periods of time may not be applicable to animals that have been bred under tropical conditions and have adapted to high environmental temperature over a period of time. The influence of the environment on animal health and production has been the subject of several comprehensive reviews (Bianca 1965; Johnson and Vanjanack 1976; Collier et al 1982).

Voluntary Feed Intake: The well-established reduction in feed intake of animals exposed to elevated temperature is a direct result of the need to maintain body temperature within defined limits. Regulation of core body temperature is normally achieved by a balance between heat loss to the environment and heat production as a result of metabolic activity within the tissues of the animal. If the animals' ability to lose heat is limited due to high environmental temperatures, the only way to prevent an increase in core temperature is to reduce heat production by lowering feed intake. Since milk production requires high metabolic activity for nutrient utilization and synthetic processes a change in intake will be rapidly translated into a fall in production. Data from Flatt et al (1969), showing that in high yielding Friesian cows 40-45% of total dietary feed energy was lost as heat from the body, underline this point and explain why high yielding animals show greatest sensitivity to heat stress whereas low yielding animals adapt more readily (Johnson et al 1967). Management systems in which animals in Nigeria were allowed to graze at night (Breinholt et al 1981) resulted in a improvement in milk production associated with increased feed intake during the hours of darkness. Similarly provision of shade, cold water and sprinkler systems which reduce the ambient temperature, will aid milk production.

The production of heat is a fundamental aspect of metabolism but whereas that associated with basal metabolism is unlikely to be readily altered, manipulation of the diet has been shown to reduce the heat increment produced as a result of feeding. It has been suggested that this effect is due to variations in volatile fatty acid production in the rumen on different diets, those which result in a high molar proportion of acetate (high roughage) being less efficiently used in terms of energy retention than those which produce a higher proportion of propionate (high concentrate) (Blaxter 1962). Interest in this area has been revived recently (MacRae and Lobley 1982); these authors suggesting that the apparently conflicting results presented in the literature can be reconciled if proper consideration is made of the protein content of the various experimental diets. Poor utilization of acetate on high roughage diets may be due to a lack of propionate to provide, via glucose, NADPH for lipid synthesis. In this situation it is unlikely that excess protein is available to provide gluconeogenenic precursors and therefore acetate is "wasted" in some form of futile cycle producing heat. This view is supported by the observation that the Heat Increment of Feeding (HIF) of autumn grass fed to sheep was 0.70 whereas that for spring grass was 0.52 despite very similar volatile fatty acid (VFA) production rates in the rumen of sheep fed the two diets (Ribiero et al, 1981). It is suggested that the increase (+ 25% N/unit Metabolisable energy intake) in nitrogen flowing to the duodenum of the animals fed spring grass permitted a more efficient utilization of the available VFA through the provision of amino acid carbon for glucose synthesis.

The relationship between crude protein intake and milk yield in cows subjected to high environmental temperatures may provide further insight into this effect. In an experiment conducted by Hassan and Roussel (1975) groups of cows were fed either 14.3 or 20.8% crude protein in the diet and their response to heat stress monitored. The high protein diet resulted in increased milk production which was associated with increased feed intake rather than crude protein intake. In addition it was noted that blood glucose concentration was higher on the high protein rations (83 mg/100 ml vs 77 mg/100 ml, N.S.) possibly indicating an improvement in glucose availability to the tissues of these animals. In a further experiment reported by Combellas and Martínez (1982) increased supplementation of the forage diet with concentrates resulted in a decreased in forage intake, as might be expected, but the increased crude protein intake from 570 g/d to 1700 g/d was linked to improvements in dry matter intake and milk yield. In this case there was a significant reduction in milk fat percentage (3.8% to 3.4%) with increasing concentrate intake suggesting that the rumen fermentation pattern had altered in favour of propionate. It is apparent that manipulation of the ration either by altering the physical form of the roughage component and therefore the VFA proportions in the rumen or by increasing the supply of protein to the small intestine are possible methods of reducing the HIF and therefore the heat load on the lactating animal.

Digestion: It has been reported that heat stress has an effect on digestion within the rumen and the small intestine although the number of observations is few. Reductions in VFA levels in the rumen are associated with lowered voluntary feed intake and it has been shown that heat stress results in a fall in acetate and propionate concentrations (Weldy et al 1964). A later study, however, in which feed intake was maintained by returning refusals to the rumen via a fistula (Kelley et al 1967) indicated that acetate molar proportion increased while that of propionate declined. Reduced rumination and rate of passage of digesta are also likely as a result of lowered intake brought about by high environmental temperature.

A more relevant consideration with respect to milk production is that of the ability of tropical feeds to promote the type of response within the animal that will result in adequate yields of milk of good quality. The addition of a wide range of concentrate feeds to diets based on tropical forage invariably results in improved animal production (Preston and Leng 1980) although responses in milk production have been variable, the reasons for which are not clear (Escobar and Combellas 1981; Gaya et al 1982; Combellas and Martínez 1982). In many of these experiments cotton seed cake has been used as a concentrate source and recent work of Sambrooke and Rowe (1982) indicates that this supplement may have a low degradability within the rumen. These authors suggest that this could limit the availability of ammonia for microbial protein synthesis unless a more soluble source of nitrogen such as urea is included in the diet.

The use of molasses in tropical feeds for ruminants has been extensively investigated and some of the characteristics of the digestion of this compound reported. Molasses-based diets result in low rumen turnover (Godoy 1980), high pH and VFA proportions which can show a marked increase in the proportion of butyrate with respect to propionate (Marty et al 1973). In addition there is evidence for secondary fermentation of acetate to carbon dioxide (Rowe et al 1979) on these diets, reducing acetate availability for absorption. These factors could combine to limit milk yield in animals fed molasses (Berry and Peña 1981), although manipulation of rumen fermentation might be an effective means of overcoming these effects and this is currently under investigation at the Facultad de Medicina Veterinaria y Zootecnia of the University of Yucatán in South East México and at the University of Newcastle upon Tyne, England. Quantification of interactions between dietary constituents is an important feature of improving our knowledge of the digestion and utilization of tropical feeds.

Metabolic and Endocrine Responses: Our understanding of metabolic and endocrine responses to tropical conditions is hampered by lack of specific data. Information derived from heat stress experiments may only reflect the short term response to the stress rather than a fundamental difference between animals maintained in a tropical environment rather than a temperate one. A recent experiment reported by Sano et al (1983), for example, indicates that when sheep are moved from a environmental temperature of 20°C to one of 30°C glucose turnover is significantly reduced (6.2 mg/kg$^{0.75}$/min to 5.1 mg/kg$^{0.75}$/min), while blood glucose concentration remained the same.

There was no change in feed intake in these animals although heat production was reduced as were plasma concentrations of non-esterified fatty acids and thyroxine (T_4). This data indicates that animals respond to heat stress by reducing metabolic rate and therefore glucose utilization. Results obtained in México from animals fed increasing amounts of rice polishing to a diet based on sugar cane (Ferreiro et al 1979), however, showed an increase in glucose entry rate with supplementation although this response was most apparent in the first few hours after feeding. In this case, it is suggested that the provision of starch in the small intestine improves glucose availability to the tissues by augmenting that available from gluconeogenesis.

Metabolite utilization by tissues is dependent upon endocrine status and heat stress has been shown to reduce insulin (Kamal et al 1970) and growth hormone (Mitra et al 1972) levels in blood. In the case of growth hormone this reduction is brought about by a fall in secretion rate from 38.2 µg/kg/d at 18°C to 21.6 µg/kg/d at 35°C resulting in a 17% reduction in the growth hormone pool in the body. Changes in hormonal balance of this magnitude will profoundly affect the pattern of nutrient utilization and therefore the production potential of the lactating animal. It is now established that nutrient mobilisation for milk synthesis is dependent upon the growth hormone/insulin ration in blood (Bines and Hart 1978; Hart 1983) and that in high producing animals this ratio tends to be high. A reduction in growth hormone secretion as shown above would limit the potential of the individual animal for milk production. Another aspect of this problem is the effect that the pattern of absorved metabolites from digestion of tropical feeds may have on hormonal status. This is an area that is currently under investigation in the U.K. with our commercial feeds but potential responses from tropical feeds may be of much greater significance. Studies by Ørskov et al (1977) showed that post-ruminal infusion of casein resulted in an increase in milk yield together with an increase in overall energy deficit. This data together with other work (Konig et al 1981) suggests that an increase in absorption of amino acids from the duodenum in the lactating cow can result in an increase in tissue mobilisation and this may be mediated by a change in growth hormone status. The use of by-pass protein supplements (Preston and Leng 1980) with tropical forages may therefore be advantageous in this area of directing metabolic responses.

A contrasting situation arises with feeds for dairy cows based on molasses. Recent data (Godoy et al 1983) show that rumen fermentation patterns that produce high molar proportions of butyrate may result in butyrate entering the peripheral blood in significant concentrations (0.22 mM). It is proposed that this situation arises when the supply of butyrate from the rumen is in excess of the capacity of the rumen mucosa for the conversion of butyrate to 3-hydroxybutyrate. The elevated concentration of butyrate appears to stimulate insulin release resulting in levels in excess of 100 µU/ml in plasma. This response, if repeated in the lactating cow, would limit production potential as insulin aids in the partition of available energy towards tissue deposition rather than milk synthesis.

Conclusion

The integration of data from a number of experimental situations provides a basis for speculation as to how milk production under tropical conditions may be improved. It is apparent that milk synthesis provides an additional stress to animals in a hot environment and that the achievement of high yields will require careful application of our knowledge of the digestion and utilization of tropical feeds. The complex interaction between nutrient uptake and endocrinological response and the influence this may have on the availability of metabolites for milk synthesis also requires further experimental work to establish the causes of observed responses to dietary manipulation. Although a discussion of management systems and breeding programmes is outside the scope of this paper it is obvious that these factors will also have an important bearing on progress in this field.

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