PRINCIPAL FEATURES OF DIGESTION IN KANGAROOS

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Summary

The most striking feature of the kangaroo stomach is its colon-like tubular morphology. This results in a tubular flow of digesta and decreasing rates of fermentation along the forestomach. Fibre digestibility is lower than in ruminants, but kangaroos are able to maintain their feed intake on high fibre diets better than can ruminants.

Less is known about rat-kangaroos. The large sacciform region and short tubiform region of the rat-kangaroo forestomach results in some bypass of the forestomach fermentation area by ingested food. Microbial fermentation may be less important, and intestinal digestion more important in rat-kangaroos, which feed on low-fibre materials, than in kangaroos and wallabies.

I. INTRODUCTION

The herbivorous marsupials can be conveniently divided into two groups, foregut fermenters and hindgut fermenters. The foregut fermenters consist of the superfamily Macropodoidea (kangaroos and rat-kangaroos). The hindgut fermenters include the wombats, koala, and several species of folivorous possums and gliders (Hume 1982).

The Macropodoidea consists of two families, the Potoroidae (rat-kangaroos) and Macropodidae (kangaroos and wallabies). Food habits range from omnivory in the smallest of the potoroids through mycophagy in other rat-kangaroos to herbivory in the true sense in the kangaroos and wallabies. The morphology of the digestive tracts of the Macropodoidea shows a close relationship with diet. Other features related to dietary habit include body size and dentition (Table 1).

II. KANGAROOS

Of the two macropodoid families much more is known about digestion in the Macropodidae than in the Potoroidae. The most striking feature of the macropodid (kangaroo) stomach is its colon-like tubular morphology (Fig. 1). Microbial fermentation occurs throughout the forestomach, in both the sacciform and tubiform regions. The hindstomach is the acid-pepsin secreting region.

The musculature of the forestomach wall is organised into three longitudinal bands (taeniae). Semi-lunar folds between the taeniae form the haustrations to give the stomach its colon-like appearance. Contractions of the haustra propel digesta caudally in such a way that fluid is expressed through the particulate digesta. As a result the 90% excretion time of fluid in the digestive tract is much shorter than that of particles (23 versus 40 h in eastern grey kangaroos fed chopped lucerne hay)(Dellow 1982). Also, the 90% excretion times of both fluid and particles are shorter than in sheep, another foregut fermenter of similar body size, fed the same diet (38 and 44 h for fluid and particulate markers, respectively) (Dellow 1982).

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Table 1. Classification, diets and digestive tract characteristics of the Macropodoidea

Superfamily	Macropodoidea			
Family	Potoroidae		Macropodidae	
Subfamily	Hypsiprymnodontinae	Potoroinae		
Example	Musky Rat-kangaroo (*Hypsiprymnodon moschatus*)	Potoroo (*Potorous tridactylus*)	Swamp Wallaby (*Wallabia bicolor*)	Red Kangaroo (*Macropus rufus*)
Habitat	Tropical rain forest	Sclerophyll forest	Forest-woodland	Forest-grassland
Diet	Omnivorous (fruit, fungi, invertebrates)	Omnivorous-herbivorous (fungi, roots, seeds)	Herbivorous Browsers	Grazers
Fibre content of diet	Low	Low	Medium	Medium-high
Body size (kg)	0.4 - 0.7	0.7 - 3.5	1.3 - 20	20 - 80
Dental action	?	crushing/ grinding	crushing	cutting
Stomach morphology	simple	complex	complex	complex
Sacciform fore-stomach as % of total stomach	-	very large	large-small	small
Tubiform fore-stomach as % of total stomach	-	very small	inter-mediate	large
Caecum and prox-imal colon as % of total gut	small	large	small	small

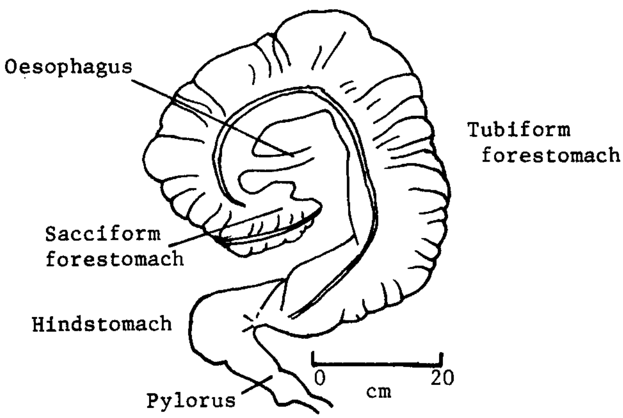

Fig. 1. The stomach of the eastern grey kangaroo (*Macropus giganteus*)

The consequences of the colon-like morphology of the stomach and the resulting rate and pattern of digesta movement in the kangaroo are two-fold. First, fibre digestibility is generally lower than in sheep fed the same diet (Dellow and Hume 1982a). Second, large kangaroos appear to be able to maintain their feed intake as the fibre content of the diet increases better than can sheep. This apparent paradox can be resolved by examining recent findings from the University of New England.

(a) Microbial fermentation and fibre digestion in the kangaroo forestomach

The kangaroo forestomach houses a dense population of bacteria (7 to 76 x 10^{10} per g contents) as well as anaerobic phycomycetous fungi and ciliate protozoa (Hume 1984). The highest concentrations of protozoa are always found in the sacciform forestomach (1.5 x 10^5 per g), and total numbers decrease progressively along the tubiform forestomach. This decline suggests that in the tubiform forestomach either dilution rates are too high, or concentrations of soluble substrates decrease along this gastric region.

Concentrations of volatile fatty acids (VFA), the principal non-gaseous end-products of microbial fermentation in the gut, and rates of production of VFA, measured both in vitro and in vivo (Dellow et al. 1983, Hume 1982), also decline along the length of the macropodid stomach. This supports the idea that as digesta move through the forestomach the substrate fermented is based progressively less on soluble cell contents and more on cell-wall constituents of the diet. That this is so is shown in Fig. 2. In the eastern grey kangaroo

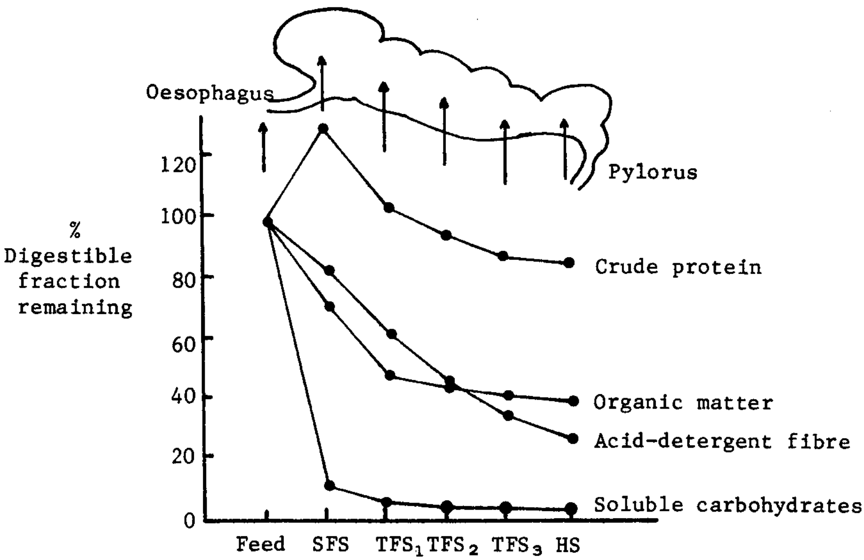

Fig. 2. The disappearance of digestible components of chopped lucerne hay along the stomach of the eastern grey kangaroo (from Dellow and Hume 1982b). SFS: Sacciform forestomach; TFS: Tubiform forestomach; HS: Hindstomach.

there was rapid disappearance of soluble carbohydrates in the sacciform region of the forestomach, while fibre was digested more-or-less uniformly along the length of the tubiform forestomach.

Despite the change in fermentation rate with distance from the cardia, the total production of VFA as a proportion of digestible organic matter intake is similar in macropodids and sheep (Dellow et al. 1983). The rate of VFA production (mmole per l per h) is in fact greater in kangaroos (Hume 1982). The lower digestibility of fibre often reported in kangaroos must therefore be a consequence of the faster passage of digesta through the macropodid stomach and thus more limited opportunity for microbial attack of the less tractable structural carbohydrates of plant cell walls, and not of a less efficient fermentation.

(b) Intake of fibrous diets by kangaroos

Although fibre digestibility is generally lower, feed intake falls less precipitously in large kangaroos than it does in sheep when the fibre content of the feed increases.

Ruminants are well equipped for maximal fibre digestion. This is achieved by prolonged retention of fibrous plant material in the reticulorumen, often for periods exceeding 60 h. However, when retention times are extreme, as they often are on high fibre diets, feed intake is limited by rumen distension as a result of the slow passage of undigested residues. The relationship between feed intake by ruminants and increasing content of cell wall constituents, one measure of fibre, is shown in Fig. 3.

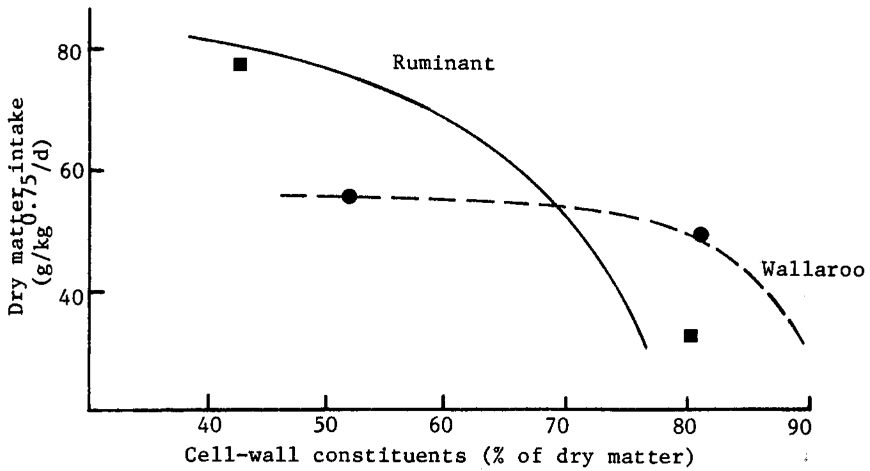

Fig. 3. Relationship between dry matter intake by ruminants (solid line) and wallaroos (Macropus robustus) (broken line) and fibre content of forages measured as cell-wall constituents. Ruminant line from Van Soest (1965). ■ Sheep, ● wallaroo data from Hollis and Hume.

Also shown in Fig. 3 are the results of a comparison of intake of chopped lucerne hay and chopped oaten straw by 40 kg sheep and 20 kg wallaroos (Macropus robustus) (Hollis and Hume, unpub.). The lower dry matter intake of the wallaroos on the low fibre diet (chopped lucerne hay) is a reflection of their lower maintenance requirements for energy (Hume 1974, 1982). However, on the high fibre diet (chopped oaten straw) dry matter intake by the wallaroos fell by only 17%, in contrast to the sheep in which intake fell by 58%. A similar difference between sheep and macropodid marsupials (in this case red kangaroos, Macropus rufus) was reported by Foot and Romberg (1965).

III. RAT-KANGAROOS

The family Potoroidae is divided into two subfamilies. The Hypsiprymnodontinae is represented by a single species, Hypsiprymnodon moschatus, the musky rat-kangaroo. It is a small omnivorous inhabitant of tropical rainforests, and its digestive tract is distinguished from all other macropodoid marsupials by a simple stomach (Table 1 and Fig. 4).

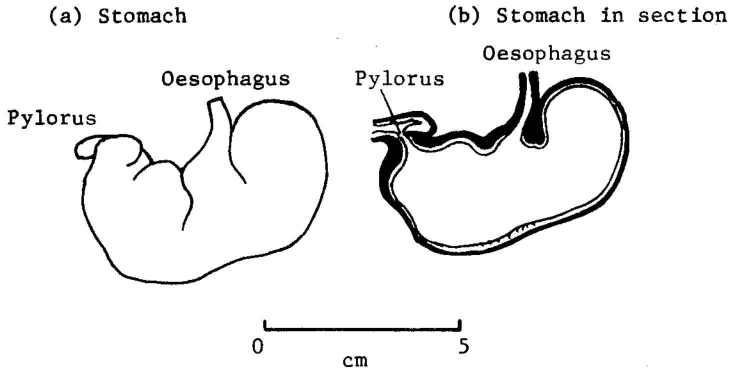

Fig. 4. The stomach of the musky rat-kangaroo. (a) external features, (b) longitudinal section. From Hume (1982).

The other potoroid subfamily, the Potoroinae, is more herbivorous (Table 1) and all members have a complex stomach which can be divided into the three principal regions described for the kangaroos, viz. sacciform forestomach, tubiform forestomach, and hindstomach (Fig. 5).

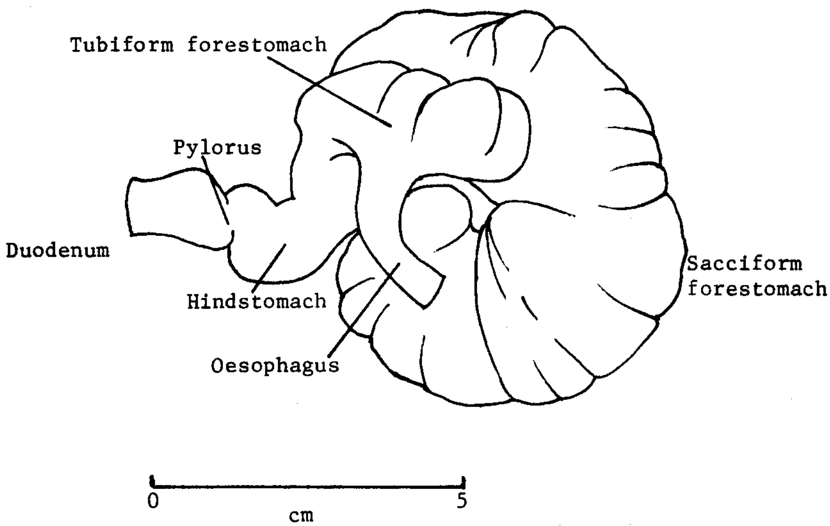

Fig. 5. The stomach of the long-nosed potoroo (Potorous tridactylus).

The main difference in gastric morphology between the Macropodidae and the Potoroinae is the large size of the sacciform region of the forestomach, and the very small size of the tubiform region in the latter group. Fermentation occurs in the sacciform forestomach (Kinnear et al. 1979), although its extent is not known. The short distance between the cardia (opening of the oesophagus into the tubiform forestomach) and the pylorus raises the possibility that some ingested food may bypass the sacciform forestomach. That this does occur has recently been confirmed radiographically (Hume and Carlisle 1984), although the extent of bypass was not established. In contrast, the morphology of the macropodid stomach dictates that all ingesta must pass through the forestomach fermentation area of kangaroos.

Bypass of the forestomach fermentation area by ingested food in the Potoroinae would seem to offer an advantage to this group which feeds on materials low in cell-wall constituents but high in readily digested cell contents. These materials would be more efficiently utilized if digested in the small intestine. Cell walls that escape fermentation in the forestomach may be fermented in the hindgut. Both the kangaroos and rat-kangaroos have a secondary fermentation in the hindgut (caecum and proximal colon), but the capacity of the hindgut, as a proportion of total gut capacity, is significantly greater in the rat-kangaroos.

IV. CONCLUSION

There is thus a close relationship within the macropodoid marsupials between dietary habits and digestive tract morphology. Digestive function has been studied in a number of species of kangaroos and wallabies. There are gross differences in gastric anatomy between these marsupials and ruminant species which are reflected in differences in the rate and pattern of digesta flow and in fermentation patterns. However, the overall efficiencies of the two fermentation systems are similar.

Comparatively little is known about digestive function in rat-kangaroos, but several features of their stomach anatomy suggest that the extent of fibre digestion may be limited.

REFERENCES

DELLOW, D.W. (1982). Aust. J. Zool. 30: 751.
DELLOW, D.W. and HUME, I.D. (1982a). Aust. J. Zool. 30: 391.
DELLOW, D.W. and HUME, I.D. (1982b). Aust. J. Zool. 30: 767.
DELLOW, D.W., NOLAN, J.V. and HUME, I.D. (1983). Aust. J. Zool. 31: 433.
FOOT, J.Z. and ROMBERG, B. (1965). Aust. J. Agric. Res. 16: 429.
HUME, I.D. (1974). Aust. J. Zool. 22: 13.
HUME, I.D. (1982). 'Digestive Physiology and Nutrition of Marsupials'. (Cambridge University Press: Cambridge).
HUME, I.D. (1984). BioScience. 34: 435.
HUME, I.D. and CARLISLE, C.H.. (1984). Bull. Aust. Mammal Soc. (In Press).
KINNEAR, J.E., COCKSON, A., CHRISTENSEN, P. and MAIN, A.R. (1979). Comp. Biochem. Physiol. 64A: 357.
VAN SOEST, P.J. (1965). J. Anim. Sci. 24: 834.