# Particularidades da Digestão em Ruminantes

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## Factores determinantes do processo digestivo nos ruminantes

- Papel central da digestão microbiana e localização das câmaras fermentativas
  - Implicações anatómicas
  - Implicações no transito digestivo
  - Implicações na eficiência e estratégias digestiva
  - Implicações da localização pré- ou pós-gastrica das câmaras de fermentação

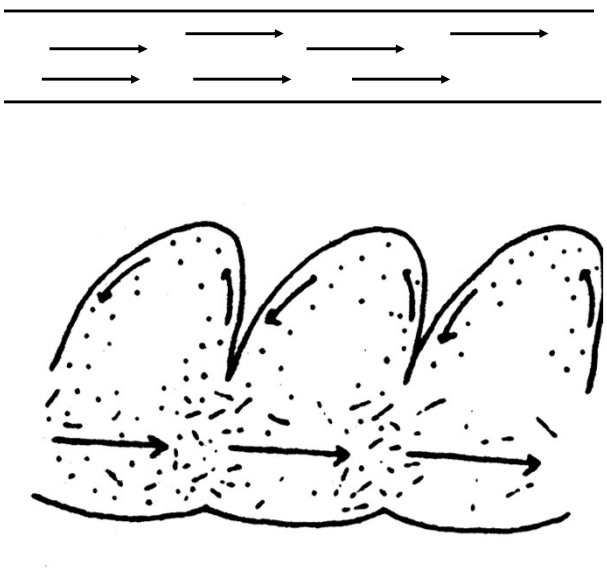
Table 3.2. Occurrence of enzymatic systems for degradation

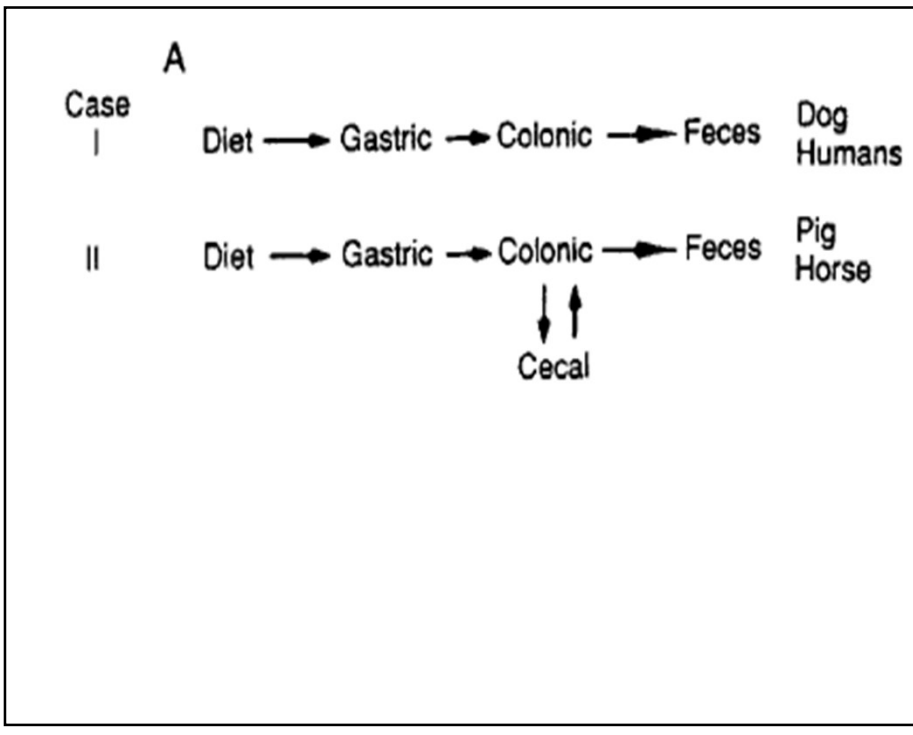
| Material | Aerobic | | Anaerobic (microbial) | |
|---|---|---|---|---|
| | Bacterial and fungal | Animal (mammalian) | GI tract | Sludge or soil |
| Sugar | + | + | + | + |
| Starch | + | + | + | + |
| Cellulose | + | − | + | + |
| Lignin | + | − | − | + |
| Keratin protein | + | − | − | + |
| Fats | + | + | − | + |
| Fossil | | | | |
| Oil | + | − | − | − |
| Coal | − | − | − | − |

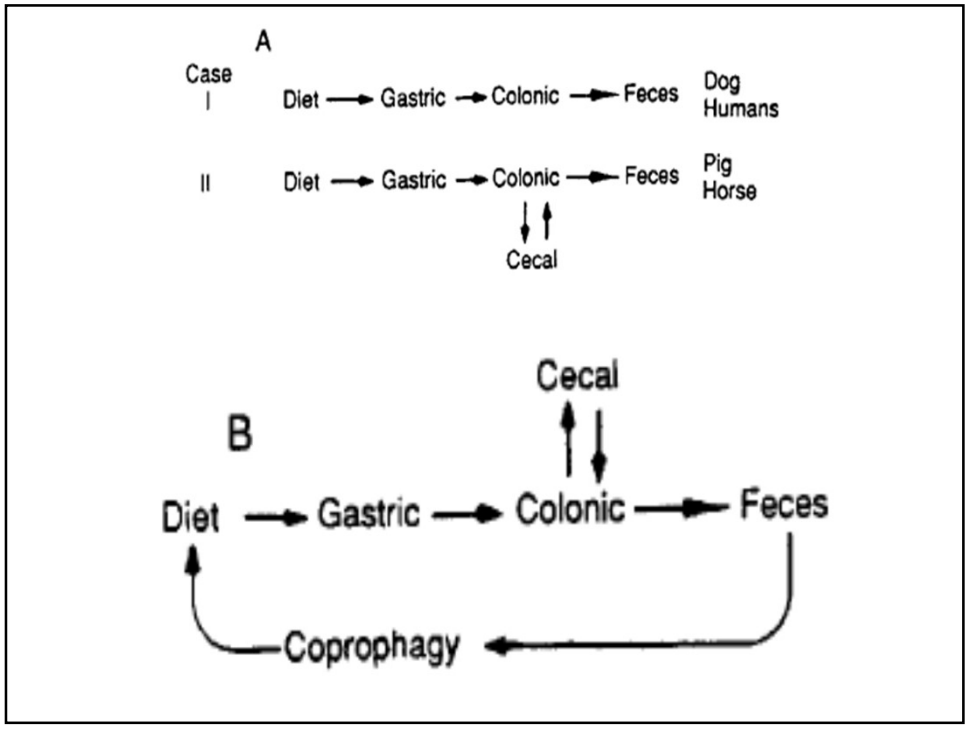
Table 5.1. Mammals classified by gastrointestinal anatomy

| Class | Species | Dietary habit |
|---|---|---|
| Pregastric fermenters | | |
| Ruminants | Cattle, sheep | Grazing herbivores |
| | Deer, antelope, camel | Selective herbivores, including folivores and frugivores |
| Nonruminants | Colobine monkey | Selective herbivore |
| | Hamster, vole | Selective herbivores |
| | Kangaroo, hippopotamus | Grazing and selective herbivores |
| | Hoatzin | Folivore |
| Hindgut fermenters | | |
| Cecal digesters | Capybara | Grazer |
| | Rabbit (lemming) | Selective herbivores |
| | Rat, mice | Omnivores |
| Colonic digesters | | |
| Sacculated | Elephant, horse, zebra | Grazers |
| | New World monkeys | Folivores |
| | Pig, human | Omnivores |
| Unsacculated | Panda | Herbivore |
| | Dog, cat | Carnivore |

*Sources:* Parra, 1978; Hume, 1982; C. E. Stevens, 1988.




A
Case
I
Diet
Gastric
Colonic
Feces
Dog
Humans
II
Diet
Gastric
Colonic
Feces
Pig
Horse
Cecal


A
Case
I
Diet
Gastric
Colonic
Feces
Dog
Humans
II
Diet
Gastric
Colonic
Feces
Pig
Horse
Cecal
B
Cecal
Diet
Gastric
Colonic
Feces
Coprophagy

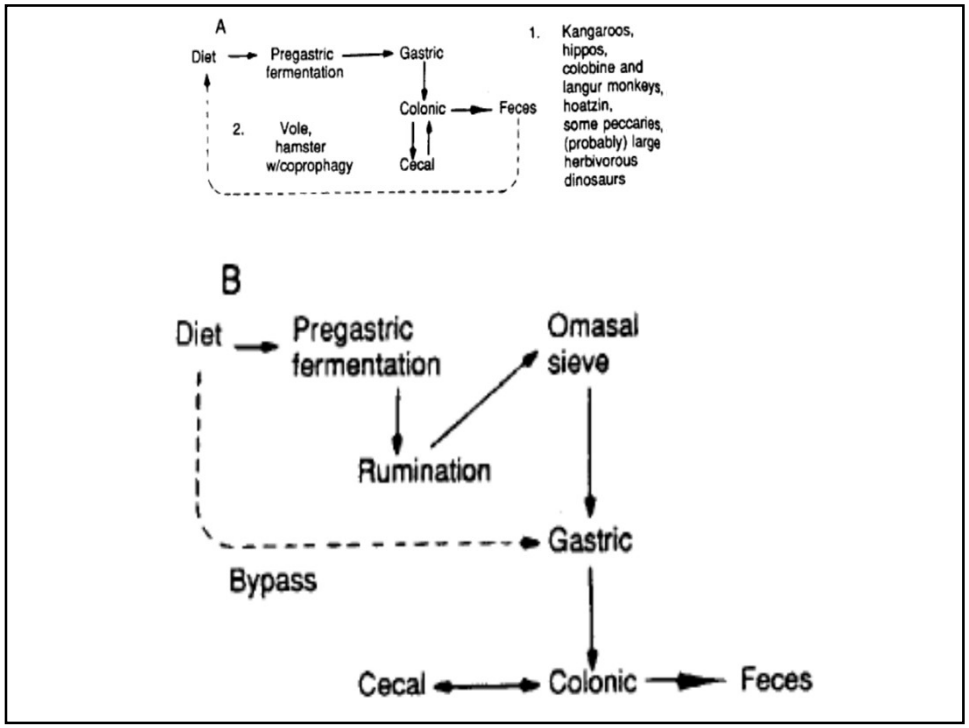

A
Diet
Pregastric
fermentation
Gastric
Colonic
Feces
2.
Vole,
hamster
w/coprophagy
Cecal
1.
Kangaroos,
hippos,
colobine and
langur monkeys,
hoatzin,
some peccaries,
(probably) large
herbivorous
dinosaurs
B
Diet
Pregastric
fermentation
Omasal
sieve
Rumination
Gastric
Bypass
Cecal
Colonic
Feces

Table 5.3. Fermentative capacity expressed as percentage of the total digestive tract for mammal species

| Species | Reticulorumen (%) | Cecum (%) | Colon and rectum (%) | Total fermentative capacity (%) |
|---|---|---|---|---|
| Sheep | 71 | 8 | 4 | 83 |
| Capybara | — | 71 | 9 | 80 |
| Cattle | 64 | 5 | 5–8 | 75 |
| Horse | — | 15 | 54 | 69 |
| Guinea pig | — | 46 | 20 | 66 |
| Rat | — | 32 | 29 | 61 |
| Rabbit | — | 43 | 8 | 51 |
| Pig | — | 15 | 33 | 48 |
| Human | — | — | 17 | 17 |
| Cat | — | — | 16 | 16 |
| Dog | — | 1 | 13 | 14 |

*Source:* Parra, 1978.

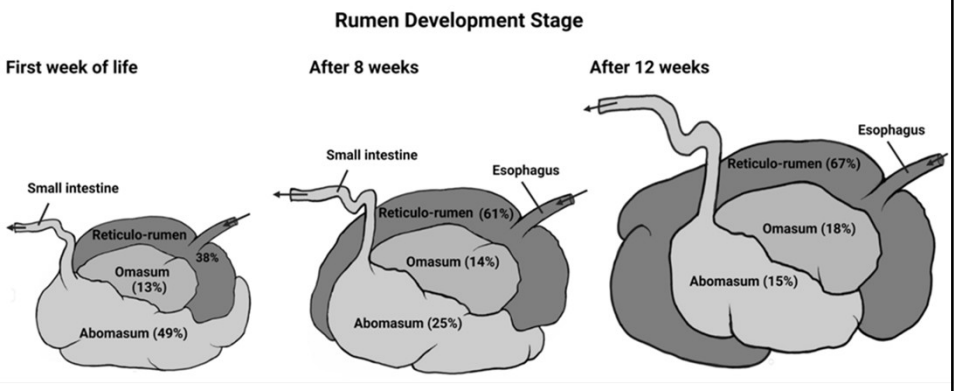


Table 17.7. Sites of disappearance of digestible cellulose and hemicellulose

| Site | Species | Diet | Cellulose | Hemicellulose | Reference |
|---|---|---|---|---|---|
| Rumen-abomasum | Sheep | Restricted to grass | 93 | 86 | Beever et al., 1972 |
| Small intestine | | | 2 | 0 | |
| Cecum + colon | | | 5 | 14 | |
| Rumen-abomasum | Sheep | Ad lib hay | 93 | 83 | Beever et al., 1972 |
| Small intestine | | | 2 | 8 | |
| Cecum + colon | | | 5 | 9 | |
| Rumen-abomasum | Sheep | Pelleted | 80 | 71 | Beever et al., 1972 |
| Small intestine | | | 2 | 5 | |
| Cecum + colon | | | 18 | 24 | |
| Postrumen | Cattle | Restricted alfalfa | 9 | 34 | Waldo, 1970 |
| Postrumen | | Ad lib alfalfa | 10 | 31 | |
| Postrumen | Sheep | Alfalfa | 10 | 20[a] | Hogan and Weston, 1967 |
| Postrumen | | Ground alfalfa | 10 | 33[a] | |
| Postrumen | | Wheaten hay | 10 | 0[a] | |
| Postrumen | | Ground wheaten hay | 31 | 41[a] | |

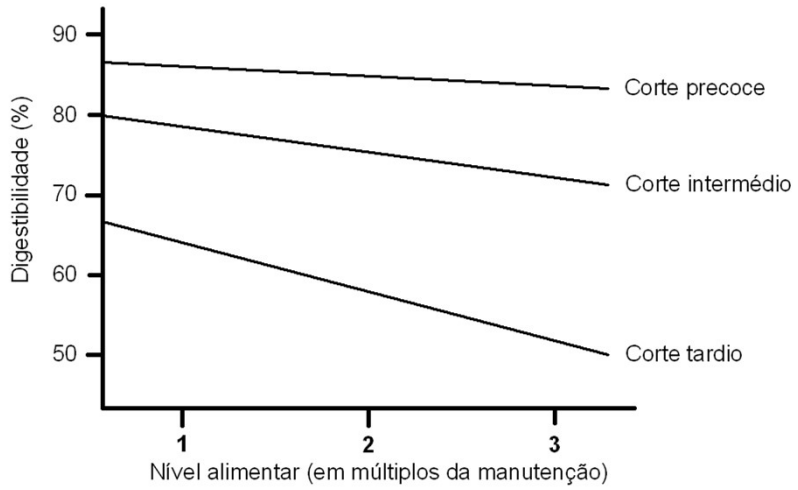
*Note:* Values are percentages of total disappearance.
[a]Calculated from original cell wall values.

Table 5.7. Comparative passage rates of liquid and particles

| Species | Body weight (kg) | Whole tract retention[a] | | Retention in fermentation compartment[b] | |
|---|---|---|---|---|---|
| | | Particles[c] (h) | Liquid (h) | Particles (h) | Liquid (h) |
| Ruminants | | | | | |
| Large heifers | 555 | 79 | 29 | 47 | 15 |
| Small heifers | 243 | 62 | 30 | 38 | 16 |
| Sheep | 30 | 70 | 38 | 35 | 19 |
| Goats | 29 | 52 | 39 | 28 | 19 |
| Nonruminants | | | | | |
| Horses | 388 | 29 | 29 | 10 | 11 |
| Ponies | 132 | 34 | 26 | 10 | 9 |
| Human | 70 | 41 | 39 | 12 | 12 |
| Rabbit | 3 | 9 | 193[d] | 4 | 180 |

Table 15.3. Effects of alfalfa hay particle size on retention time and fiber digestibility

| Feed | Mean size (μm) | 5% transit (h) | Retention 80 – 5 (h)[a] | Fiber digestibility (%) |
|---|---|---|---|---|
| Long hay | — | 22 | 54 | 44 |
| Coarse grind | 434 | 16 | 39 | 34 |
| Medium grind | 393 | 16 | 44 | 31 |
| Finely ground | 280 | 13 | 27 | 22 |




Efeito do nível de ingestão alimentar em ovinos na digestibilidade de azevém cortado em diversas fase do seu desenvolvimento (Demarquilly e Jarrige, 1981).

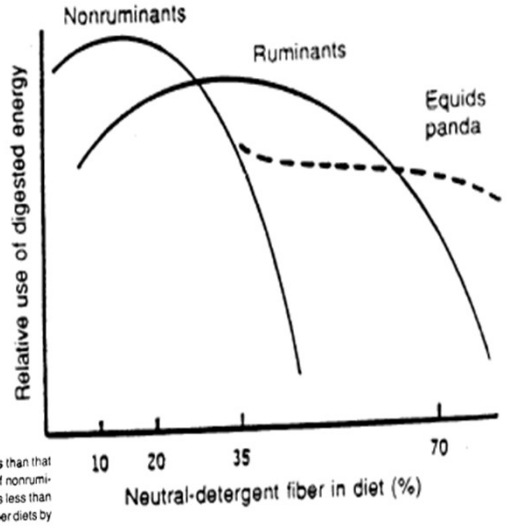
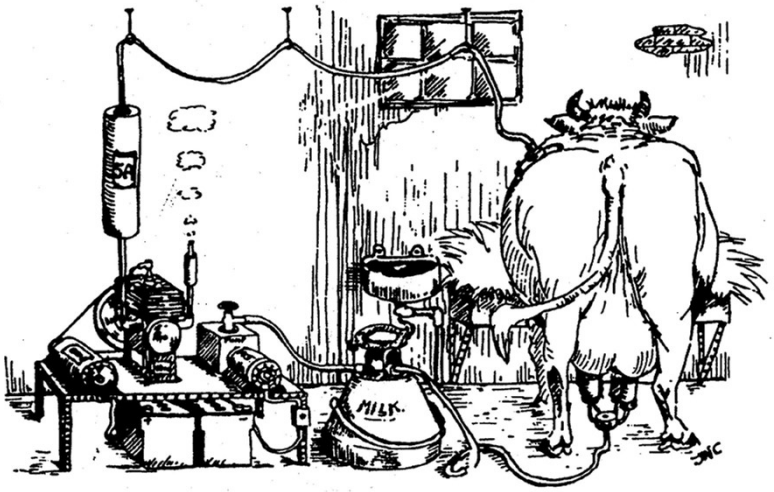



**Figure 5.14.** The optimum fiber level for nonruminants is less than that for ruminants because microbial protein is lost in the feces of nonruminants and their digestive capacity for fibrous carbohydrates is less than ruminants' capacity. A few nonruminants tolerate very high fiber diets by increasing intake to achieve their requirements from nonfiber components. This results in fast passage and low fiber digestibility. Ruminants fail on low-quality very high fiber diets because of the cost of rumination and other digestive work required to eliminate lignified fiber from their complex gut. (From Van Soest, 1985.)



Hospedeiro condiciona o ecossitema ruminal:

- Ingestão de alimento (intermitente)
- Fluxo e diluição (saliva, ingestão de água, parede ruminal, passagem)
- Ruminação e movimentos ruminais
- Temperatura, pH, potencial redox
- Imunidade ou outras forma de controlo da micropopulação ?!!

Componentes presentes no rúmen:

- Partículas alimentares
- População microbiana
- Material endógeno
- Produtos finais da fermentação

Simbiose hospedeiro aeróbio e comunidade microbiana ruminal anaeróbia

Vantagens para o hospedeiro:

- possibilidade de aproveitar abundantes recursos alimentares celulósicos obtendo :
  - AGV (fontes de energia em aerobiose e esqueletos carbonados)
  - Biomassa microbiana (proteína, lípidos e vitaminas)

Vantagens para a comunidade microbiana ruminal:

- habitat sustentável no tempo com:
  - Ambiente aquoso com dinâmica suficiente para promover a mistura mas permitindo o tempo necessário para a celulólise.
  - Abastecimento regular de água e de substrato (alimento) já sujeito a maceração mecanica.
  - Eliminação de produtos finais do seu metabolismo.
  - Condições ambientais estáveis (pH, temperatura, potencial redox e pressão osmótica).

## Ecossistema retículo-ruminal

Condições ambientais

- Anaerobiose
- Excesso de H (pressão redutora)
- Temperatura (38 a 40°C)
- pH
- Pressão osmótica
- Taxas de passagem da fase líquida e sólida
- Subtractos disponíveis
- Inúmeros nichos especializados

Alguns dados sobre o ecossistema retículo-ruminal

| | Retículo-Rumen | |
|---|---|---|
| | Ovinos | Bovinos |
| Volume, L | 7 (5-10) | 70 (40-100) |
| Fluxo, L/d | | |
| Saliva | 10 (8-16) | 120 (60-160) |
| Água (bebida) | 2 (1-3) | 35 (20-40) |
| Água (alimentos) | 2,5 (2-3) | 4,5 (3,-5,5) |
| Concentrações | | |
| MS (g/l) | 60 (50-100) | |
| Bactérias (n°/ml) | $10^{10}$ - $10^{11}$ | |
| Protozoários | $10^{5}$ - $10^{6}$ | |
| Propriedades | | |
| PH | 7 (5,0 - 7,5) | |
| Eh (mv) | -350 (-200 - -400) | |
| **Pressão osmótica** (mosmol) | 250 - 350 | |

## Teores em Vitaminas na Dieta e Rúmen

| | Dieta | Rúmen |
|---|---|---|
| Tiamina | 2- 18 | 3 - 29 |
| Riboflavina | 5- 27 | 7 - 37 |
| Niacina | 11- 91 | 46 - 233 |
| Pantothenic | 23- 42 | 17 - 56 |
| Biotina | 0,04 - 0,47 | 0,13 - 1,16 |
| $B_{12}$ | Residual | 1,1 - 3,0 |

## Ecossistema Retículo-ruminal

A Summary of the Relationships Between the Microorganisms and the Host Animal

| Process | Outcome |
|---|---|
| Salivary output | Dilution and flow<br>Buffering action<br>Steady supply of nitrogen |
| Rumination | Breakdown of food<br>Aeration?<br>Increased salivation? |
| Rumen movement | Mixing of contents<br>Emptying<br>Sequestration |
| Gas production | Eructation<br>Surface tension effects<br>Absorption |
| Absorption through wall | Removal of end products<br>Maintenance of pH<br>Maintenance of temperature |

## Secreção Salivar e Sua Função

**Funções:**

- Humedicimento e lubrificação dos alimentos
- Constitui 70 a 90 % dos líquidos contidos no rúmen
- Neutralização da acidez provocada pela produção de ácidos orgânicos
- Manter o pH entre 5,8 e 7
- Possui substancias anti-espumantes
- Neutralização de taninos
- Reciclagem de N ( ureia )

## Secreção Salivar e Sua Função

Table 15.6. Effect of ration on saliva production and eating rate

| Feed | Eating rate (g food/min) | Salivary production (ml/min) | Salivary production (ml/g food) |
|---|---|---|---|
| Pelleted ration | 357 | 243 | 0.68 |
| Fresh grass | 283 | 266 | 0.94 |
| Silage | 248 | 280 | 1.13 |
| Dried grass | 83 | 270 | 3.25 |
| Hay | 70 | 254 | 3.63 |

*Source:* C. B. Bailey, 1958.

**Tamponamento**

**Retículo-ruminal**

Table 15.7. Factors contributing to rumen buffering

| | Promoted by | Buffer source |
|---|---|---|
| Washout (passage) | Osmotic pressure<br>Feed intake | Dilution |
| Absorption | VFA concentration | Removal of free acid |
| Saliva | Coarse fiber and rumination | Bicarbonate<br>Phosphate |
| Fiber | Cation exchange | Neutralization |
| Mineral salts of plant organic acids | Forage composition | Fermenting of plant acids to $CO_2$ |
| Protein | $NH_3$ production | Neutralization |
| Microbial efficiency | Microbial growth | Diversion of carbon to cells instead of acids |

Absorção da mucosa retículo-ruminal

Absorção de AGV

A maioria dos AGV é absorvida no retículo-rúmen

pH 6 - 7 , 95 % dos AGV estão sob a forma ionizada

↓ pH ⟶ ↑ Taxa de Absorção

- Difusão simples das formas não ionizadas
- Difusão facilitada das formas ionizadas

## Metabolismo dos AGV no epitélio ruminal

**Acetato** (C2)

→ pouco metabolizado no ep. ruminal (1 a 30%)

**Propionato** (C3)

→ pouco metabolizado no ep. ruminal ( 5 a 30%)

→ convertido a lactato

**Butirato** (C4)

→ extensa metabolização (90%)

→ conversão a acetoacetato, β-hidroxibutirato

## Absorção através da mucosa retículo-ruminal

Absorção de ácidos gordos cadeia média e longa

- Até C10 são absorvidos
- A partir de C12 já não são absorvidos

## Ácidos gordos voláteis (AGV)

| | Peso molecular | pKa | E.B. (kcal/mol) | Concentrações molares | | |
|---|---|---|---|---|---|---|
| | | | | Concen-trado | Forragem | Mista |
| C2 | 60,05 | 4,75 | 209,4 | 55 | 70 | 65 |
| C3 | 74,08 | 4.87 | 367,2 | 25 | 15 | 20 |
| C4 | 88,10 | 4.81 | 524,3 | 15 | 10 | 10 |

## Absorção através da mucosa retículo-ruminal

Absorção de Amónia

Base fraca com pKa = 9

pH 6 - 7 , 99 % da amónia está sob a forma ionizada

↓ pH → ↓ Taxa de Absorção

Difusão simples da forma não ionizada

## Absorção através da mucosa retículo-ruminal

### Absorção de Amino ácido e peptideos

- AA - pouco expressiva (baixas concentrações ruminais)
- Peptideos - alguma

### Absorção de vitaminas

- Pouco expressiva

### Absorção de Minerais

- 80% do magnésio é absorvido no rúmen
- Sódio, Cálcio, Enxofre

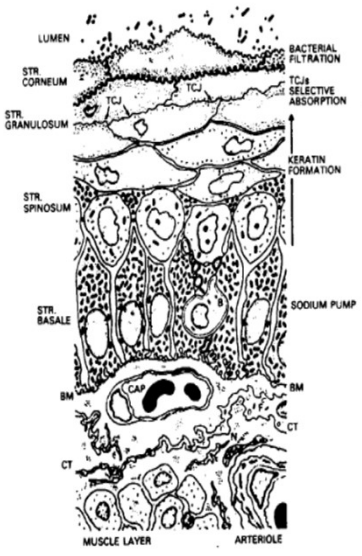
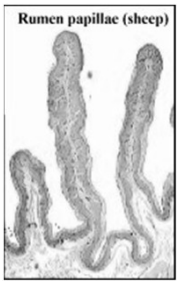
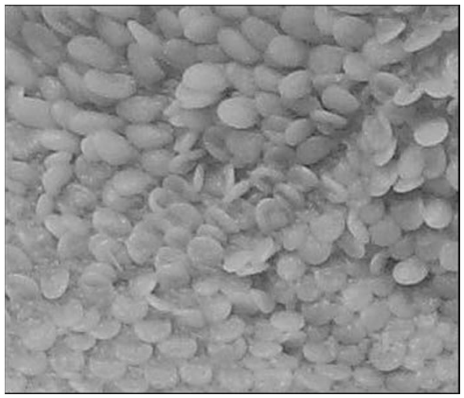



**Figure 15.4.** Cross section of the fully developed rumen wall depicting the types of cells and layers present (from D. H. Steven and Marshall, 1970). Details of the cell junctions are omitted. B = branching cell; BM = basement membrane; CAP = capillary; CT = connective tissue; F = fibroblast; N = nerve trunk; TCJ = tight cell junction.



Secreção de ureia

↑ Concentração ruminal de $CO_2$ e Butirato

↓

Difusão simples

↑ Fluxo de ureia através do epitélio

População microbiana com ureases na parede ruminal

Regulação da permebilidade do epitélio à ureia

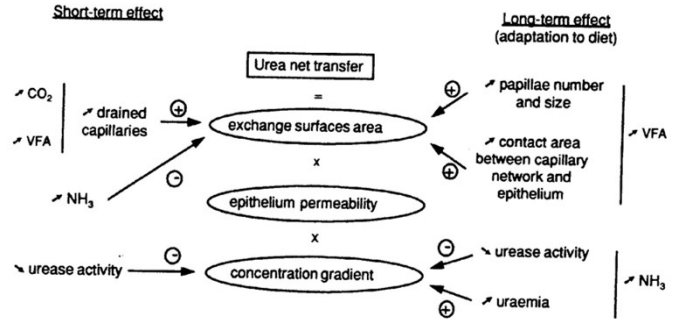



**Fig 3.** Intraruminal factors having short- or long-term effects on the urea flux across the ruminal epithelium, and the assumptions concerning their actions.

Componente microbiano no ecossistema retículo-ruminal

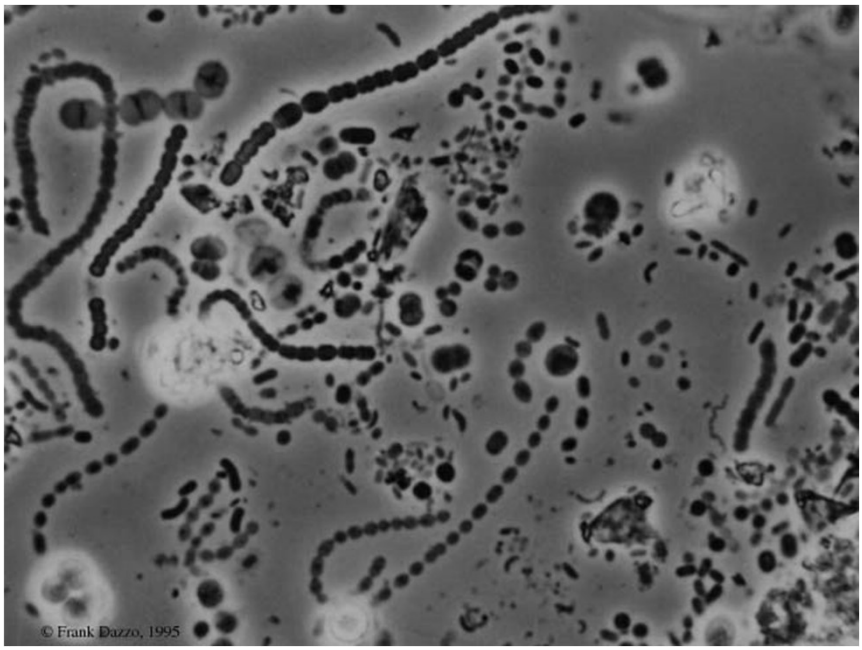
Fagos

Archeas (metanogéneos)

Bactérias

Protozoários

Fungos




## Ecossistema retículo-ruminal

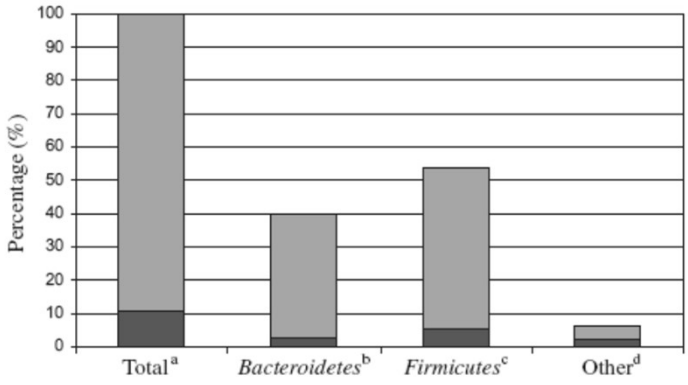



**Figure 1** The uncultivated bacterial diversity of the rumen. The percentage of operational taxonomic units (OTU) represented by uncultivated (light grey) and cultivated bacteria (dark grey) for the [a]total rumen bacterial biota is shown (Edwards *et al.*, 2004). The phylum

Examples of Relationships Between Rumen Microorganisms.
Based on various papers and review articles, e.g. El-Shazly *et al.*, 1961; Eadie, 1967; Coleman and Laurie, 1974a, b; Jarvis, 1968; Ball, 1969; Pittman and Bryant, 1964; Prins, 1977; Wolin, 1975; Czerkawski, 1978a

*Competitive*
1. Competition for nitrogen by starch and cellulose digesters.
2. Protozoal antagonisms (e.g. *ophryoscolex* and *epidinum*).
3. Ingestion of protozoa and bacteria by protozoa.
4. Attack of selected bacteria by bacteriophage (e.g. *Fibrisolvens* compared with *S. bovis*).
5. Fungal infection of some protozoa.

*Beneficial* (*to one partner*)
1. Utilization of breakdown products of fibre digestion by inhabitants of compartments 1 and 2 (Chapter 5).
2. Utilization of substances known to be produced, but not accumulating (e.g. succinate, formate, lactate).
3. Utilization of tetrapyroles by microorganisms that possess cytochrome b, but cannot synthesize it.
4. Use of preformed glycolytic intermediates in synthesis (including acetate).
5. Use of branched-chain volatile fatty acids by cellulolytic microorganisms.
6. Use of amino acids and peptides released during fermentation and lysis.

*Beneficial* (*to both partners*)
1. Many scavenging reactions, in which the removal of products improves conditions.
2. Known couplets, particularly those that suffer from product inhibition.

## Bactérias

- Livres (fase líquida)
- Aderentes às partículas (60 a 90 %)
- Aderentes às paredes ruminais
- Simbióticas com protozoários

**Tabla 3.2:** ***Principales bacterias ruminales degradan los polisacáridos de la pared celular.***

| Polisacáridos pared celular | Espec |
|---|---|
| Celulosa | *Bacteroides succinoge* |
| | *Ruminococcus flavefaci* |
| | *Ruminococcus all* |
| | *Butyrivibrio fibrisolv* |
| | *Cillobacterium cellulosolv* |
| | *Clostridium lochhea* |
| | *Cellulomonas fi* |
| | *Eubacterium s* |
| Hemicelulosa | *Butyrivibrio fibrisolv* |
| | *Ruminococcus flavefaci* |
| | *Ruminococcus all* |
| | *Bacteroides ruminac* |
| Sustancias péptidas | Todas las especies celulol cas y hemicelulolíticas m |
| | *Lachnospira multipa* |
| | *Streptococcus bo* |
| | *Succinovibrio dextrinosolv* |

Fuente: Cheng et al (1984)

Table 7-1. Grouping of rumen bacterial species according to the type of substrates which are fermented.

**Major Cellulolytic Species**
*Bacteroides succinogenes*
*Ruminococcus flavefaciens*
*Ruminococcus albus*
*Butyrivibrio fibrisolvens*

**Major Hemicellulolytic Species**
*Butyrivibrio fibrisolvens*
*Bacteroides ruminicola*
*Ruminococcus* sp.

**Major Pectinolytic Species**
*Butyrivibrio fibrisolvens*
*Bacteroides ruminicola*
*Lachnospira multiparus*
*Succinivibrio dextrinosolvens*
*Treponema bryantii*
*Streptococcus bovis*

**Major Amylolytic Species**
*Bacteroides amylophilus*
*Streptococcus bovis*
*Succinimonas amylolytica*
*Bacteroides ruminicola*

**Major Ureolytic Species**
*Succinivibrio dextrinosolvens*
*Selenomonas* sp.
*Bacteroides ruminicola*
*Ruminococcus bromii*
*Butyrivibrio* sp.
*Treponema* sp.

**Major Methane-Producing Species**
*Methanobrevibacter ruminantium*
*Methanobacterium formicicum*
*Methanomicrobium mobile*

**Major Sugar-Utilizing Species**
*Treponema bryantii*
*Lactobacillus vitulinus*
*Lactobacillus ruminus*

**Major Acid-Utilizing Species**
*Megasphaera elsdenii*
*Selenomonas ruminantium*

**Major Proteolytic Species**
*Bacteroides amylophilus*
*Bacteroides ruminicola*
*Butyrivibrio fibrisolvens*
*Streptococcus bovis*

**Major Ammonia-Producing Species**
*Bacteroides ruminicola*
*Megasphera elsdenii*
*Selenomonas ruminantium*

**Major Lipid-Utilizing Species**
*Anaerovibrio lipolytica*
*Butyrivibrio fibrisolvens*
*Treponema bryantii*
*Eubacterium* sp.
*Fusocillus* sp.
*Micrococcus* sp.

| Género | Composición (%) Material de pared celular vegetal | Líquido ruminal |
|---|---|---|
| *Butyrivibrio* | 32 | 7 |
| *Selenomonas* | 14 | 10 |
| Spirochaete sin nombre | 8 | 0 |
| *Lachnospira* | 8 | 1 |
| *Megasphaera* | 0 | 11 |
| *Streptococcus* | 3 | 12 |
| *Ruminococcus* | 16 | 6 |
| *Bacteroides* | 11 | 38 |
| Otras | 8 | 15 |
| Número total de cepas aisladas | 368 | 292 |
| Cantidad viable (cfu $ml^{-1} \times 10^7$) | 230 | 201 |

Fuente: Phillips B y Latham MJ, datos sin publicar (citados por Cheng el al 1984)

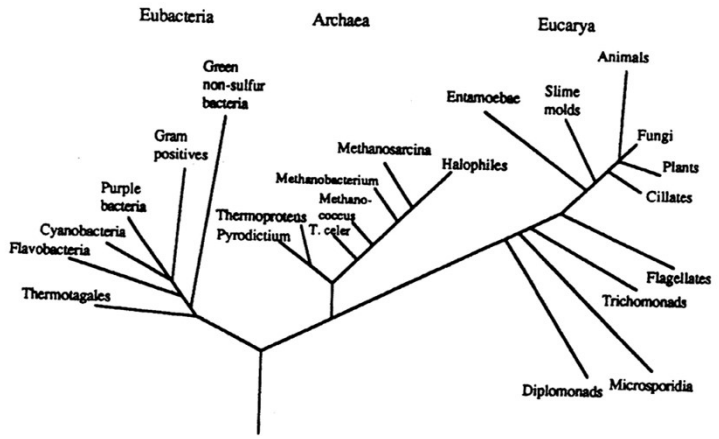
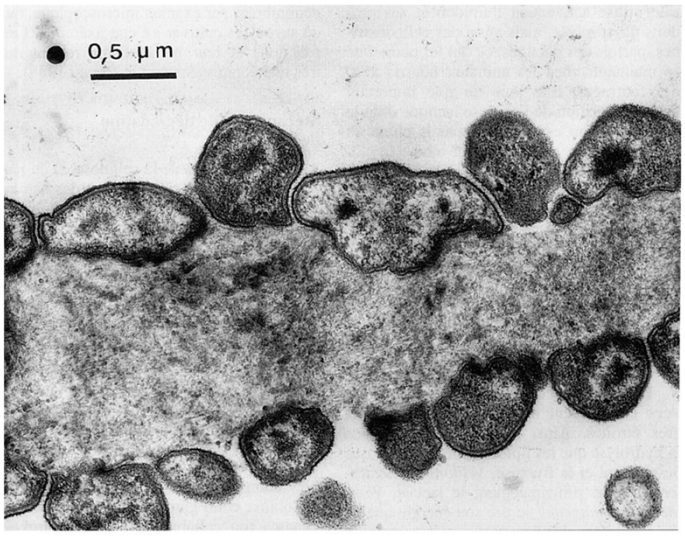



Figure 1. Rooted tree of phylogenetic relationships among Eubacteria, Archaea, and Eucarya. Redrawn from Wheelis et al. (81).




**ure 8.1.** *Fibrobacter succinogenes* adhérant à une fibre de cellulose (culture bactérienne de h sur papier filtre). Cliché INRA, labo. de Microbiologie, Clermont-Fd-Theix.

**Micropopulação aderente ao epitélio retículo-ruminal**

**Figure 8.8.** Bacilles adhérant à la muqueuse du rumen chez un jeune agneau (1 barre = 10 µ). Cliché INRA, labo. Microbiologie, Clermont-Fd-Theix.

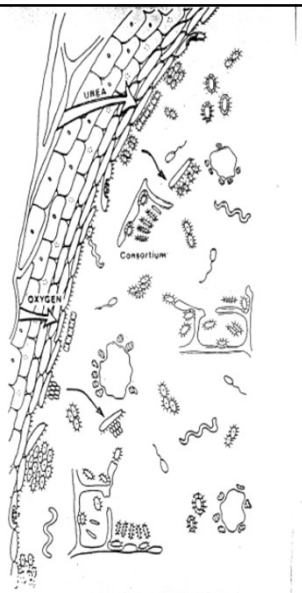



Figure 8-1. Locations of microbes in the rumen with facultative anaerobes found near the epithelial cells of the rumen wall and anaerobes partially associated with plant cell walls, starch particles or floating free. From Cheng and Costerton (7).

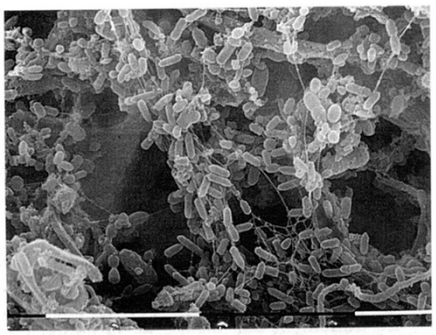


**Figure 10.5.** Bactéries fixées sur les parois cellulaires de pulpe de betterave (cliché E. Grenet)

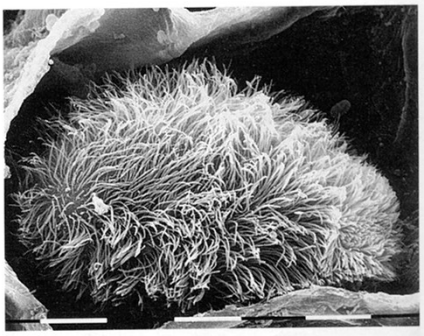


**Figure 10.6.** Protozoaire cilié (cliché E. Grenet).

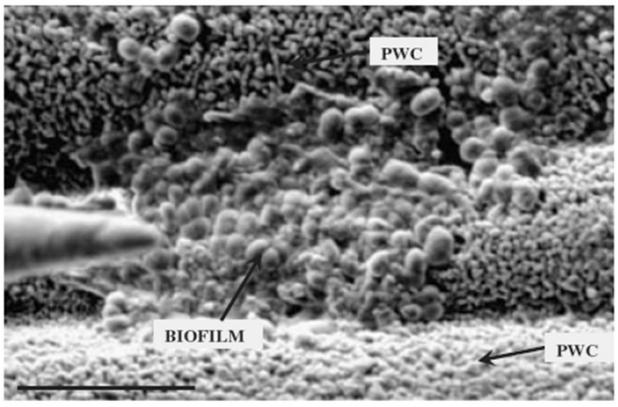
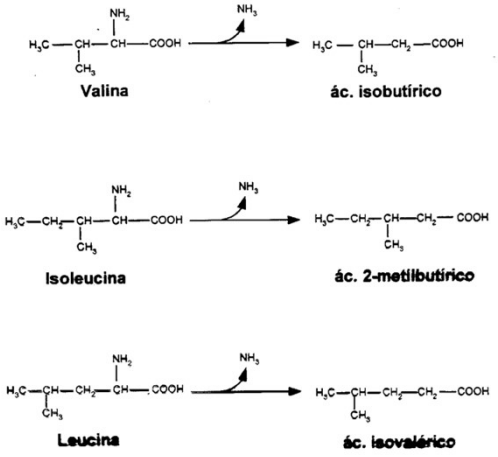



**Figure 2** Microbial feed-associated biofilms. Scanning electron microscopy image of a biofilm community present on the adaxial surface of *Lolium perenne* following 2 h of incubation in the presence of rumen fluid and under *in vitro* conditions mimicking the rumen ecosystem (Mayorga *et al.*, 2007). The plant waxy cuticle (PWC) and the scale bar of 10 μm are also indicated on the image.

**Bactérias Celulolíticas (fibrolíticas):**
(Butyrivibrio fibrosolvens, Ruminococus albus, R. flavefaciens, Bacteroides succinogenes, B. ruminicola)

- Anaeróbias estrictas
- Extremamente sensíveis a pH abaixo de 6
- Necessitam de AGV ramificados para crescer
- Baixas taxas de crescimento
- Aderência às partículas
- Enzimas (glucanases extracelulares: xilanases, celulases, )

**Necessidades em AGV ramificados da bactérias celulolíticas**



**Bactérias Amilolíticas e utilizadoras de açucares**
(Streptococcus bovis, Succinimonas amylolytica, Bacteroides amylophilus, Lactobacilus spp)

- Mais resistentes ao baixos pH
- Crescimento mais rápido
- Amilase extracelulares

**Bactérias Utilizadoras de ácidos intermédios (lactato, sucionato, valerato, formato, etc)**

(Megasphaera elsdenii, Selenomonas ruminatium)

# Metanogénese no rúmen

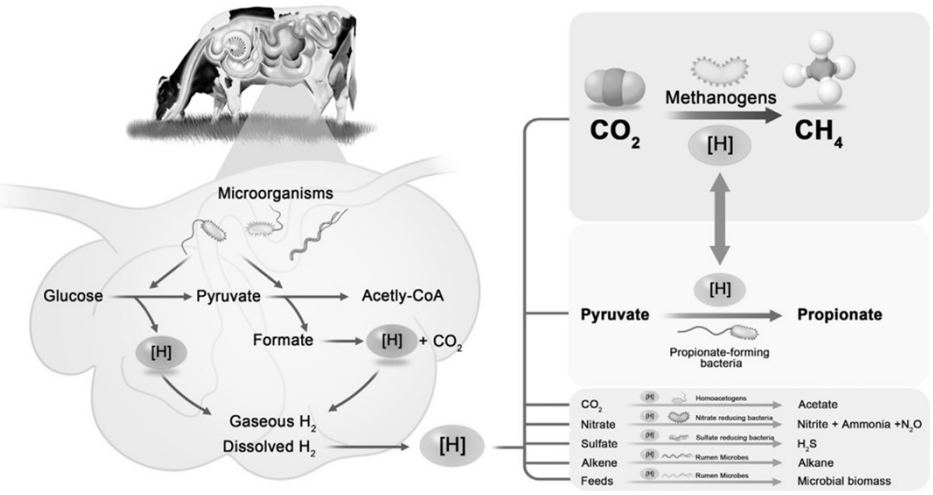
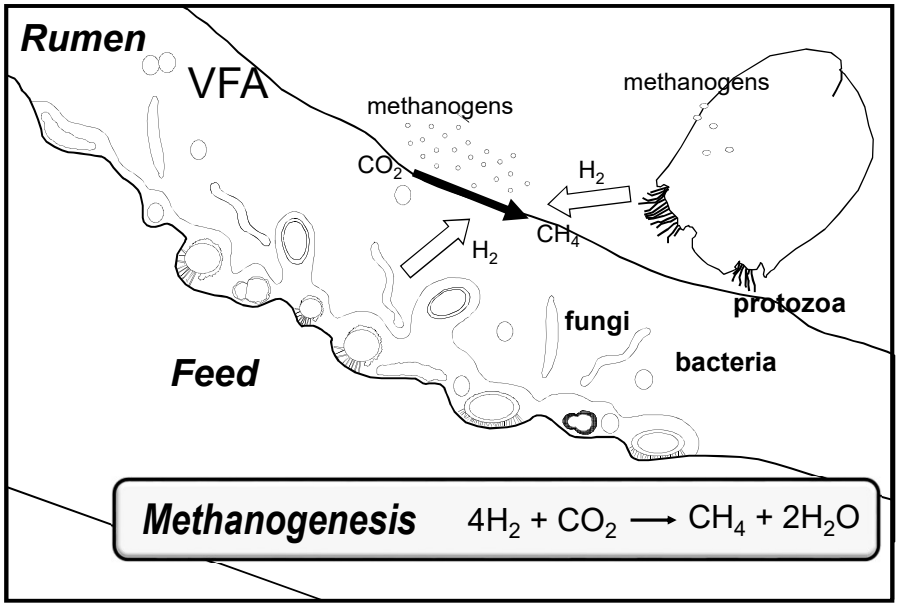
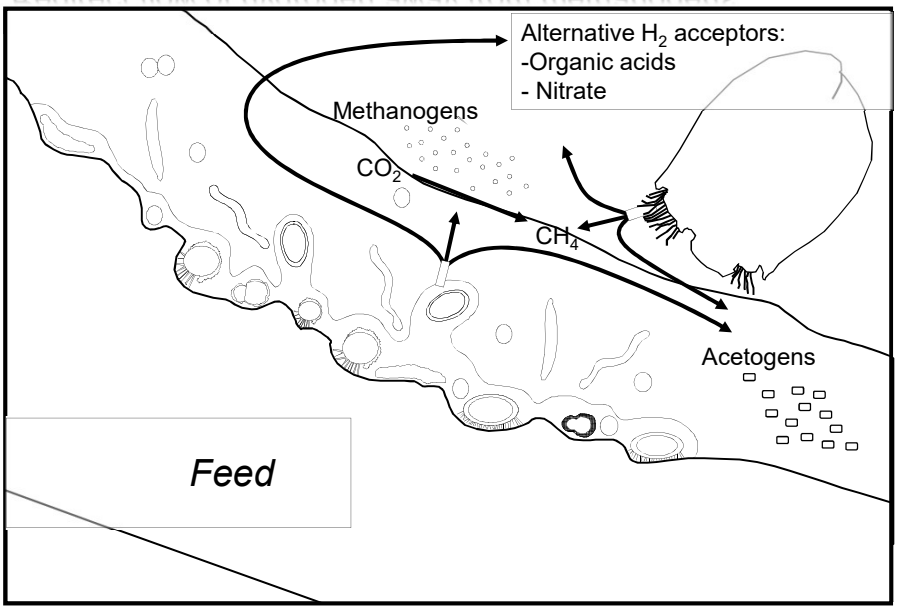


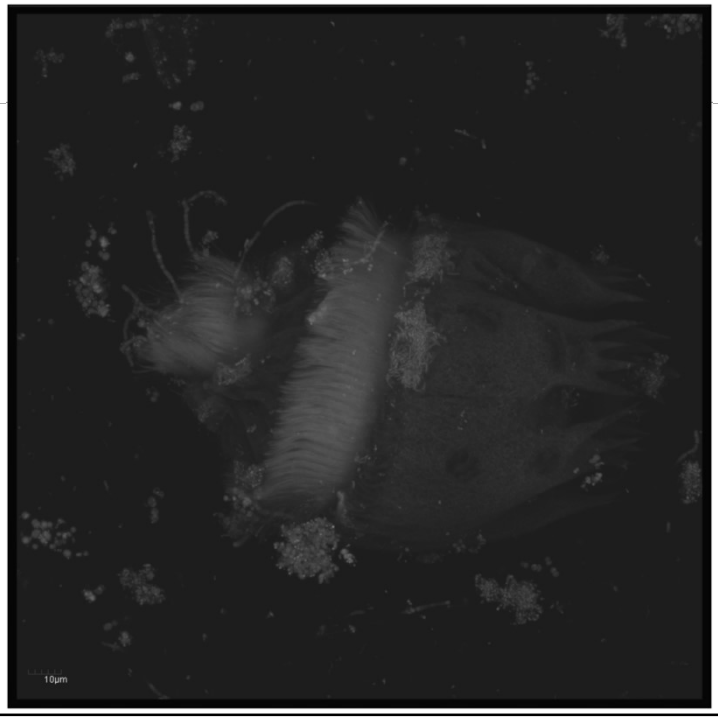

**Fig. 5.** A brief overview of the biochemical pathways for disposal of $H_2$ in the rumen.

## Methane Production in the Rumen

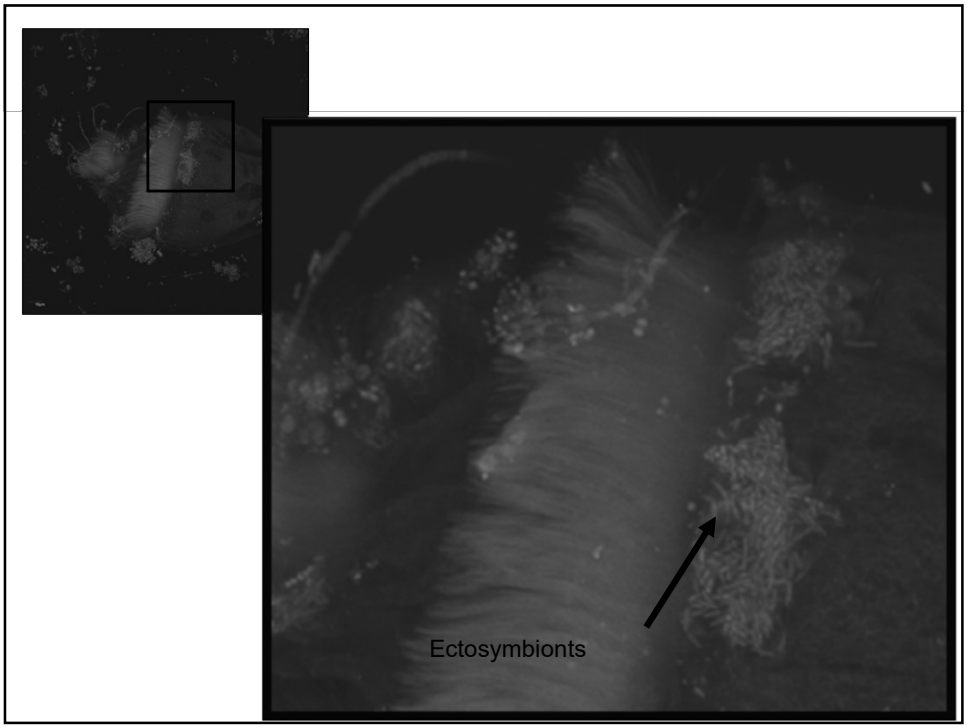



*Redirect flow of hydrogen away from methanogens*

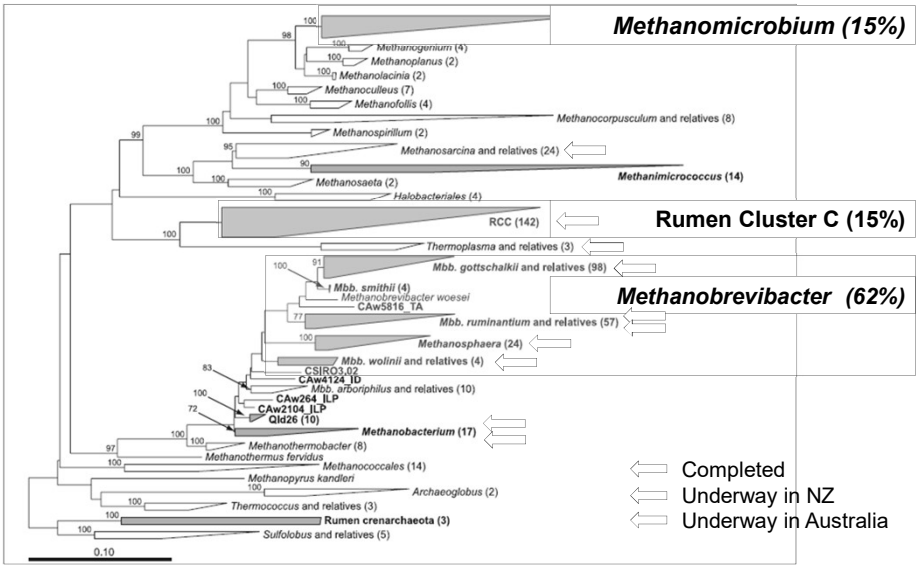




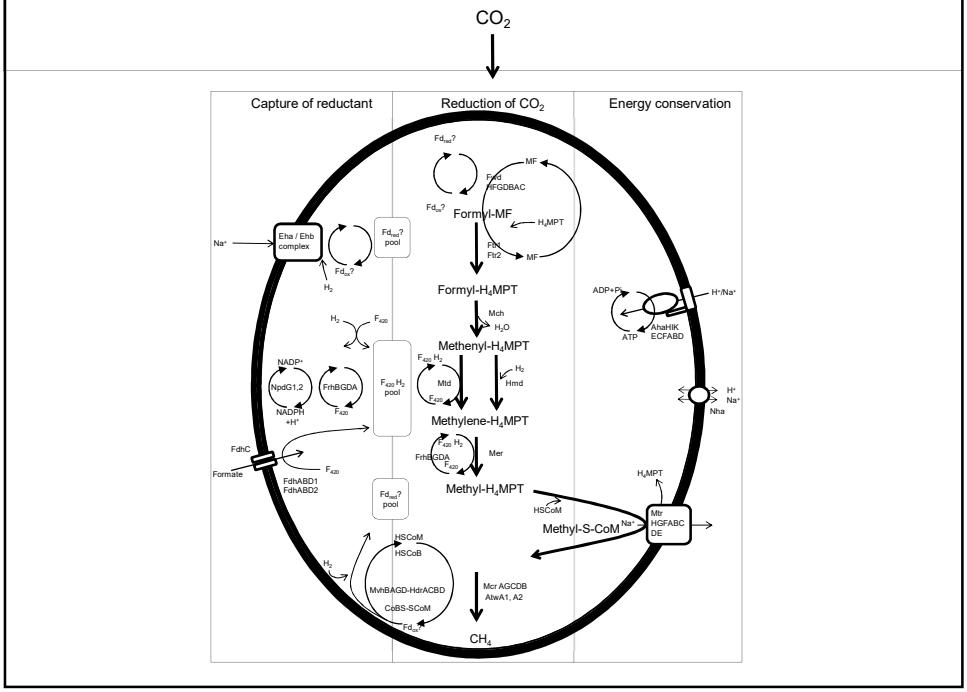

30-40% $CH_4$ in rumen



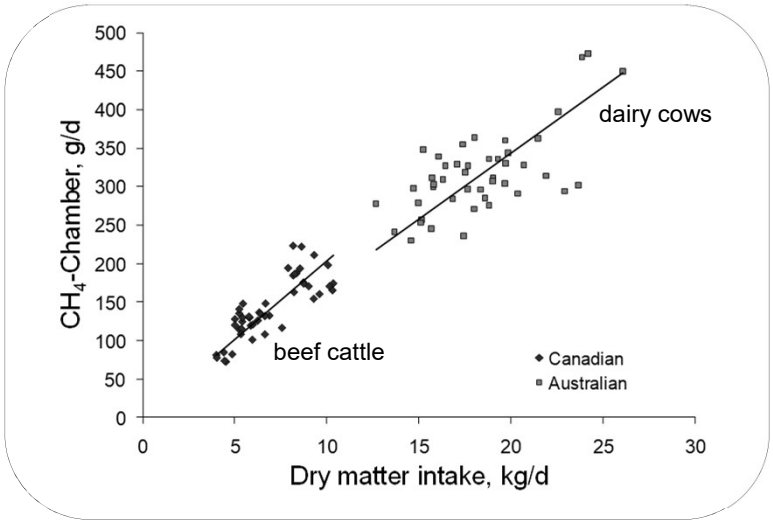
# Rumen methanogen diversity




*Janssen and Kirs, 2008*



# Methane Emission and Dry Matter Intake




Grainger et al. 2007. J. Dairy Sci. 90:2755.

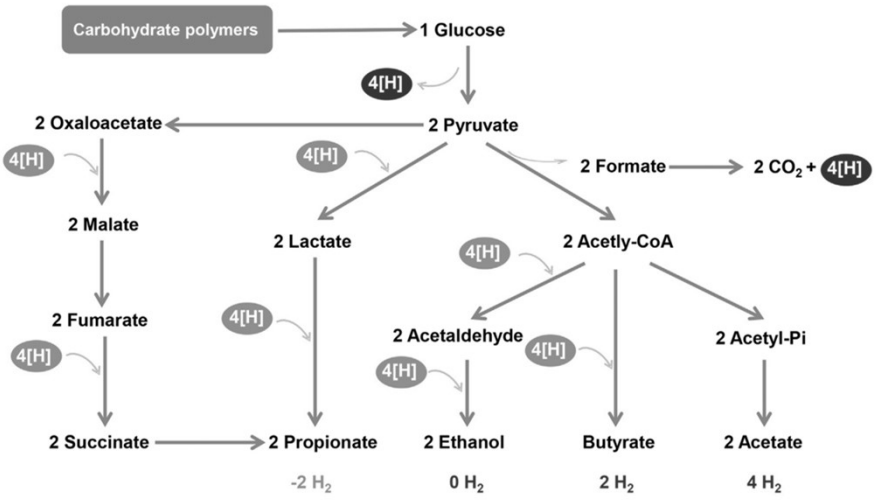



**Fig. 2.** Production and consumption of metabolic hydrogen ([H]) during rumen volatile fatty acids production.

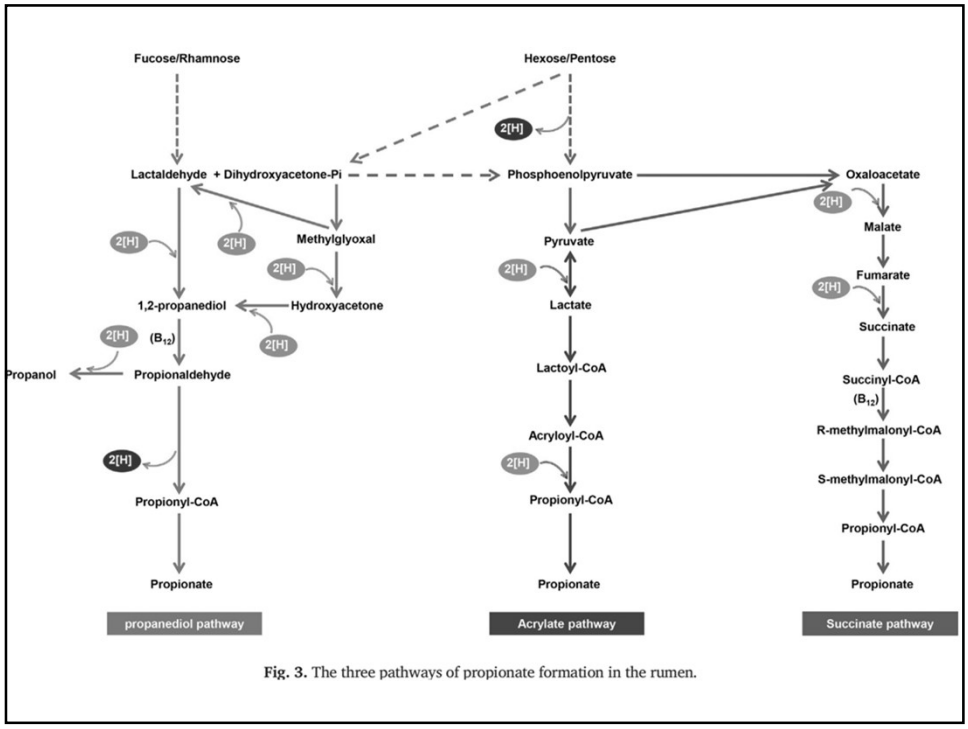



**Fig. 3.** The three pathways of propionate formation in the rumen.

The characteristics of different strategies that potentially promote propionate formation.

| Strategies | Mechanism of mitigation | Effects on propionate | Effects on $CH_4$ | Potential problems |
|---|---|---|---|---|
| Ionophores | Inhibition of microbes that produce $H_2$ or formate | Medium | Medium | • Bacterial resistance<br>• Residues |
| Halogenated compounds | Inhibition of methanogens | Low | High | ◇ Toxicity<br>◇ Residues<br>◇ Bacterial resistance |
| Plant secondary compounds | A broad spectrum of antimicrobial activity | Medium | Medium | • Costs<br>• Bacterial resistance<br>• Negative effects on performance |
| Lipids | Inhibition of methanogens and protozoa | Medium | Medium | ◇ Costs<br>◇ Negative effects on performance |
| Nitrooxy compounds | Inhibition of methanogens | Low | High | • Costs<br>• Potential bacterial resistance |
| Propionate precursors | Competing with methanogenesis for [H] | High | Low | ◇ Costs<br>◇ Inefficiency |
| Concentrates | Competing with methanogenesis for [H] | High | Medium | • Costs<br>• The risk of ruminal acidosis |
| Forages | Lowing $CH_4$ emission per unit of meat and milk | Non | Non | ◇ Increasing the absolute emission |
| Non-forage fiber sources | Competing with methanogenesis for [H] | Low | Low | • Inefficiency |

## Metanogénese

Permite que os microorganismos produtores de $H_2$ utilizem vias metabólicas com maior rendimento em ATP

- Aumenta o rendimento microbiano (proteína microbiana)

- Aumenta a actividade fibrolítica (maior digestão da fibra)

Por outro lado representa uma perda de energia disponível para o metabolismo do animal

Stoichiometry of Fermentation of Glucose by Two Rumen Organisms Grown in Continuous Culture (Based on the Values Given by Iannotti *et al.*, 1973)

| | Amounts (mol/100 mol glucose) | |
|---|---|---|
| Products | *R. albus* alone | *R. albus* with *V. succinogenes* |
| Ethanol | 69 | 0 |
| Acetate | 74 | 147 |
| $H_2$ | 237 | 0 |
| Succinate | 0 | 384 |

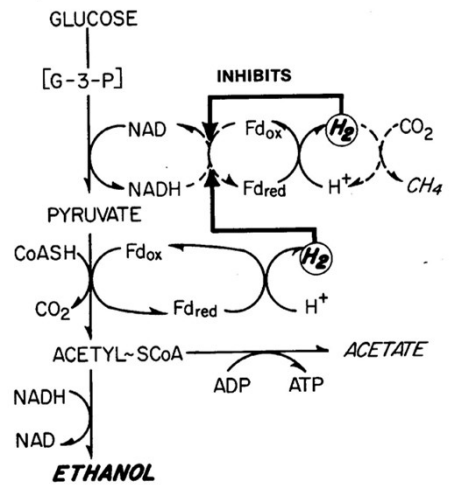
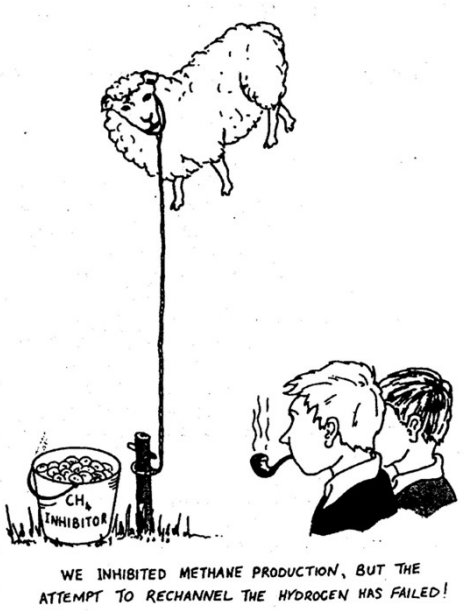



Figure 7-3. Fermentation of *Ruminococcus albus* in pure culture and in co-culture with a methanogen. Acetate, ethanol, $H_2$ and $CO_2$ are end-products in pure culture, while only acetate and $CH_4$ are end-products in co-culture. Courtesy of Wolin and Miller (60).

**Balanço da Produção de ATP (~P) e de equivalentes redutores (2H) nas diversas vias de fermentação**

| | Lactato | Acetato | Propionato | Butirato | Etanol | Valerato |
|---|---|---|---|---|---|---|
| Total (~P) | 2 | 4 | 4 | 3 | 2 | 2 |
| Total (2H) | 0 | 4 | -2 | 2 | 0 | -1 |




## Protozoários ciliados

- Entidinomorfos
- Holotricos

Predadores: Aumentam a reciclagem de N no rúmen

Ingestão de partículas

Digestão de celulose !?!

Simbiose com bactérias metanogénicas

Não são indispensáveis

Table 16.4. Classification and characteristics of rumen protozoa

| Genus | Probable main carbohydrate substrate | Cellulose digestion | Products[a] | Approximate generation time (h) |
|---|---|---|---|---|
| Holotrichs | | | | |
| *Isotricha* | Starch and sugars[b] | 0 | 2,3,La,$H_2$ | 48 |
| *Dasytricha* | Starch and sugars | 0 | 2,3,La,$H_2$ | 24 |
| Entodiniomorphs | | | | |
| *Entodinia* | Starch | 0(+) | 1,2,3,4,(La) | 6–15 |
| *Epidinium* | Starch, hemicellulose | 0 | 2,3,$H_2$,(1,3,La) | |
| *Ophryoscolex* | Starch[b] | 0 | 2,3,$H_2$,(3) | 24–48 |
| *Diplodinium* | | + | | |
| *Eudiplodinium* | | + | $H_2$,fatty acids | |
| *Polyplastron* | | + | | 48 |

*Source:* Hungate, 1966.

*Note:* Morphological features of the rumen protozoa are described in Hungate, 1966, and Church, 1975.

[a] Abbreviations are from Table 16.2; parentheses indicate a minor product.

[b] Pectinolytic, but do not seem to utilize products.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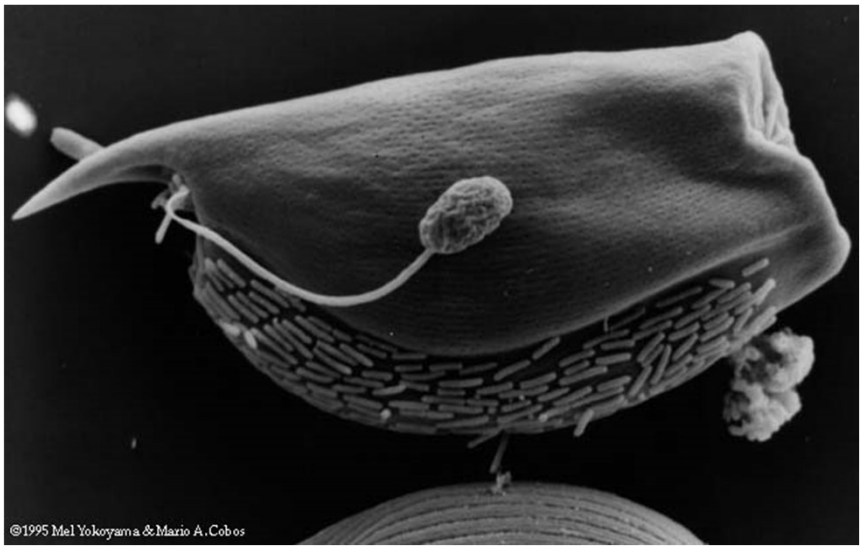
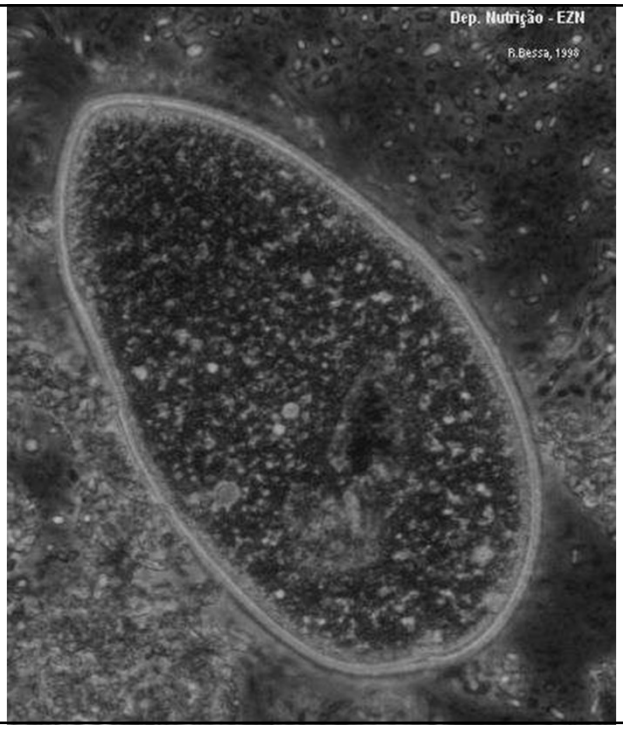
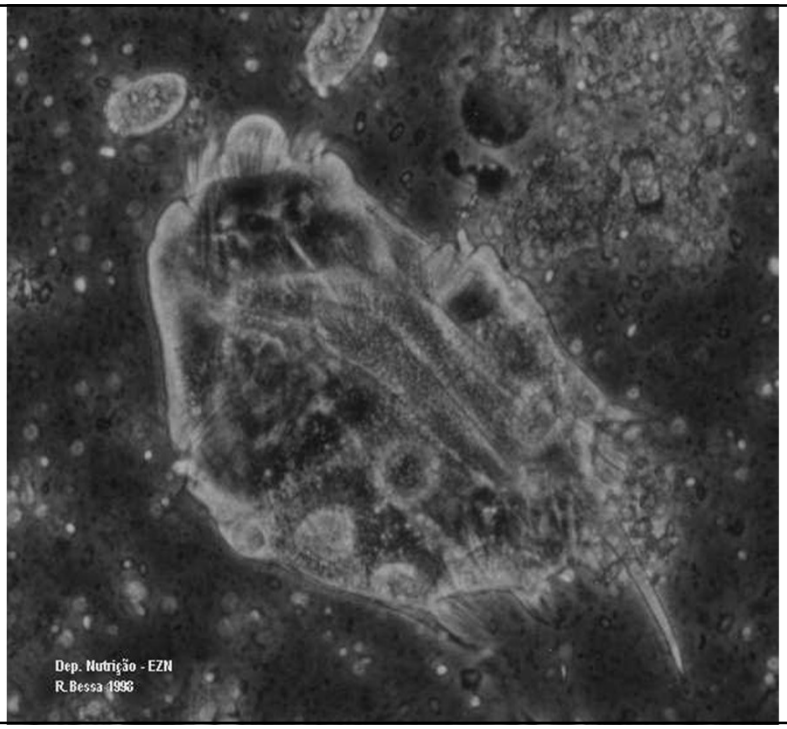
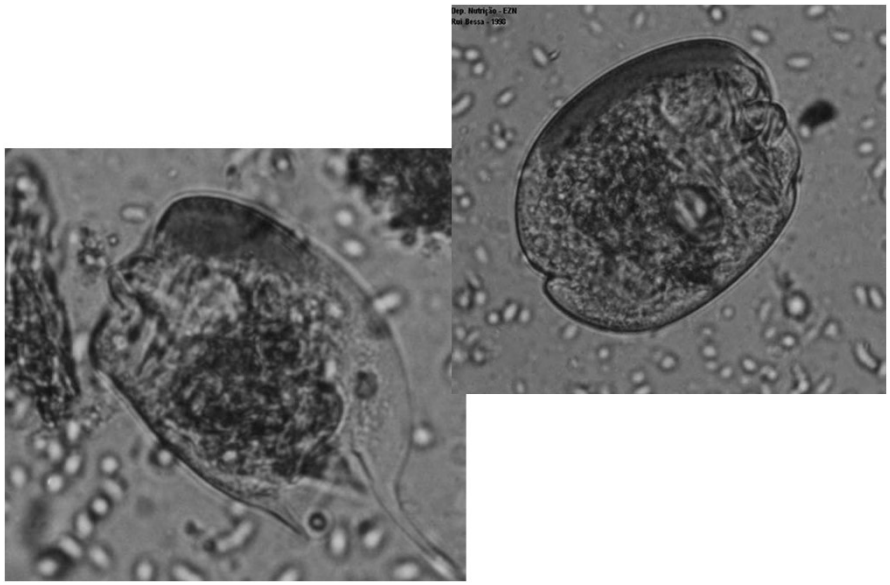

©1995 Mel Yokoyama & Mario A. Cobos


Dep. Nutrição - EZN
R.Bessa, 1998


Dep. Nutrição - EZN
R.Bessa 1998



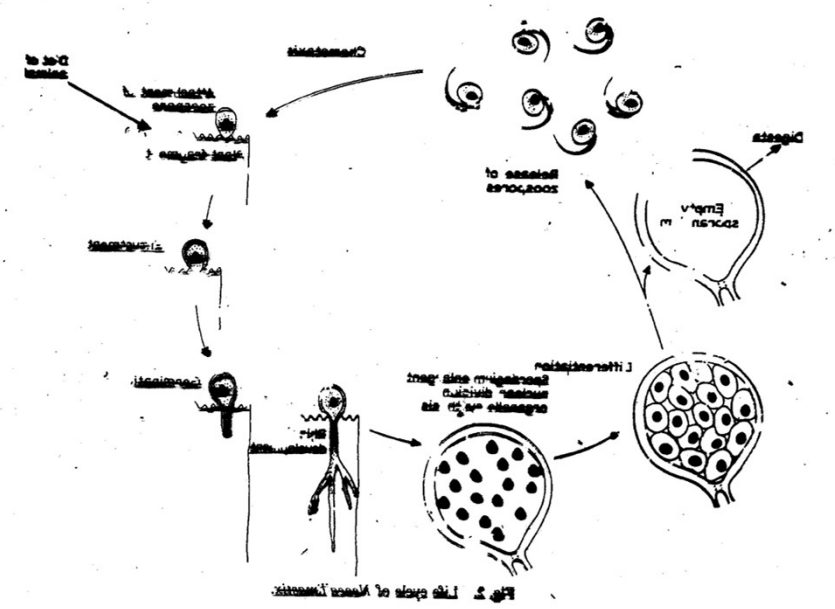
## Fungi

Anaeróbios

Presentes em maior número em dietas pobres

-Zoosporos
- germinação
- rizóide

http://www.goatbiology.com/animations/funguslc.html



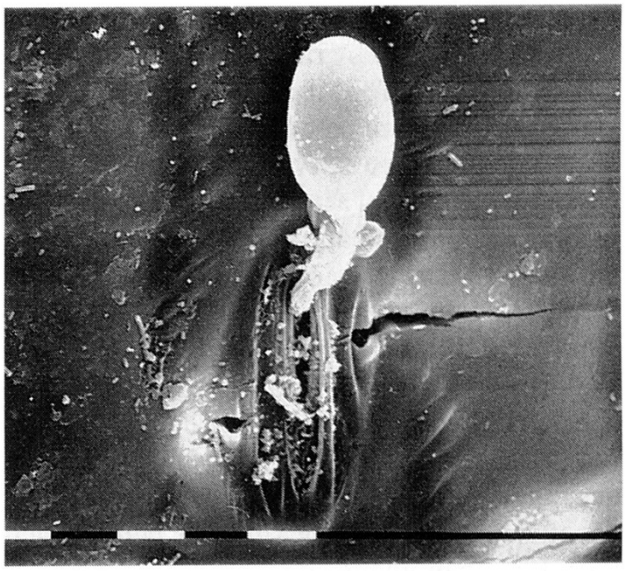


**Figure 10.7.** Champignon (cliché E. Grenet).

**Micropopulação aderente ao epitélio retículo-ruminal**

**Figure 8.8.** Bacilles adhérant à la muqueuse du rumen chez un jeune agneau (1 barre = 10 µ). Cliché INRA, labo. Microbiologie, Clermont-Fd-Theix.

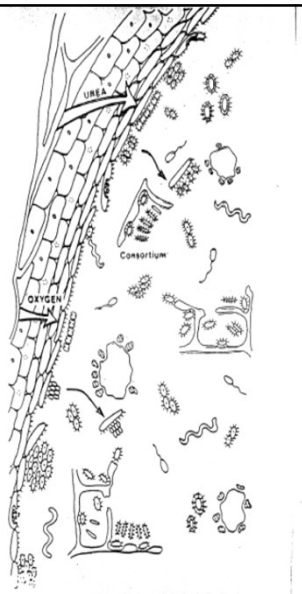
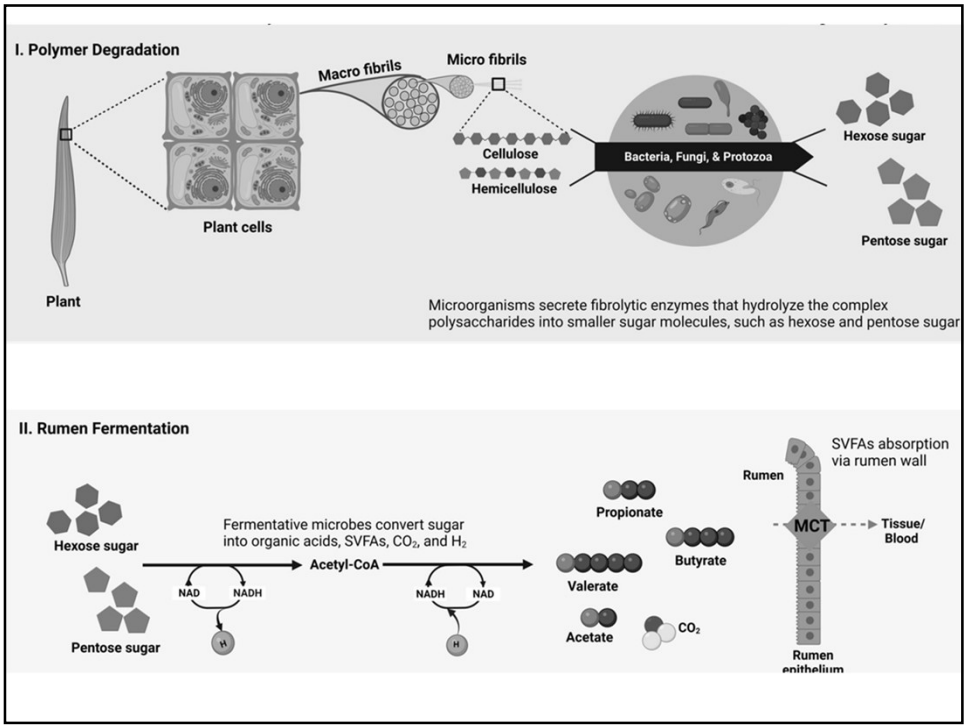
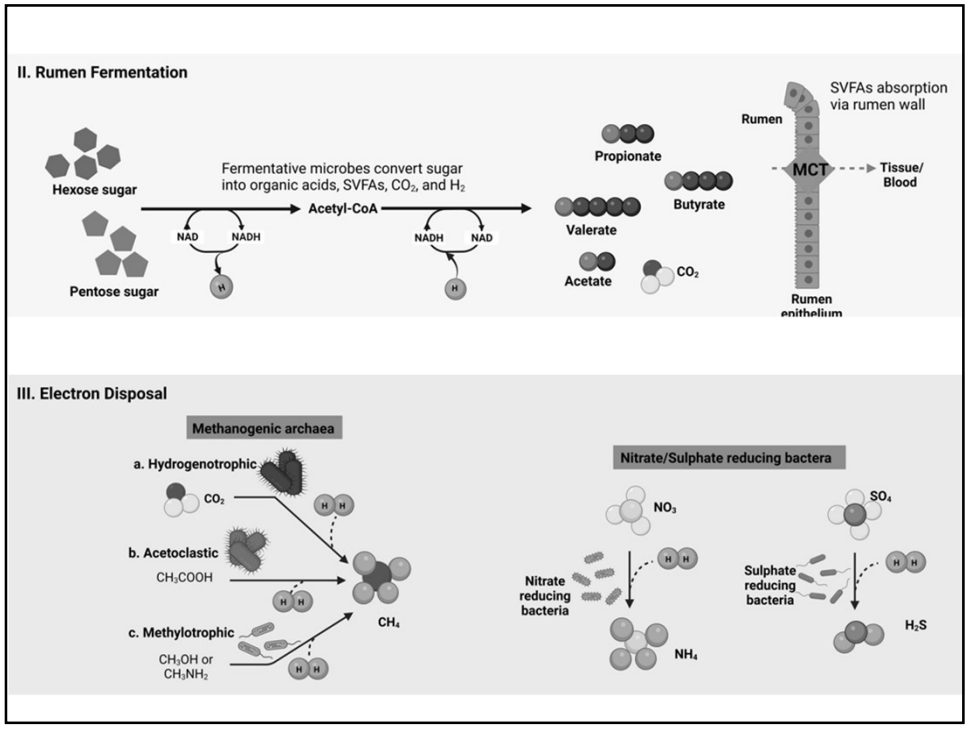



Figure 8-1. Locations of microbes in the rumen with facultative anaerobes found near the epithelial cells of the rumen wall and anaerobes partially associated with plant cell walls, starch particles or floating free. From Cheng and Costerton (7).






# Degradação da MO e produção de AGV

- Extensa degradação dos polissacarídeos e outro material orgânico
- Colonização das partículas vegetais por biofilmes microbianos
- AGV, $CO_2$ e $CH_4$ são os produtos finais do metabolismo anaeróbio ruminal
- Síntese de biomassa microbiana (proteína; vitaminas e lípidos)

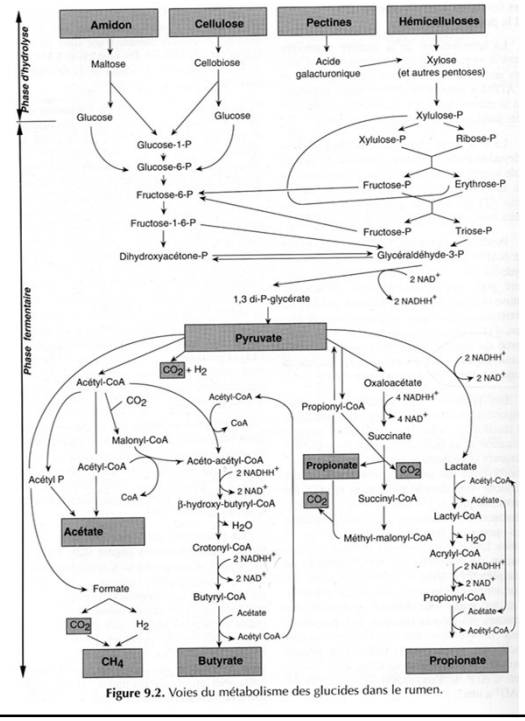



**Figure 9.2.** Voies du métabolisme des glucides dans le rumen.

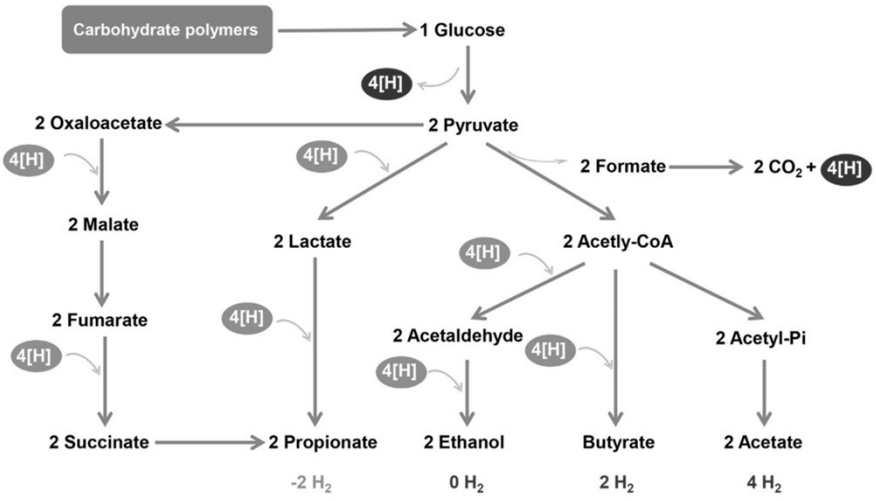



**Fig. 2.** Production and consumption of metabolic hydrogen ([H]) during rumen volatile fatty acids production.

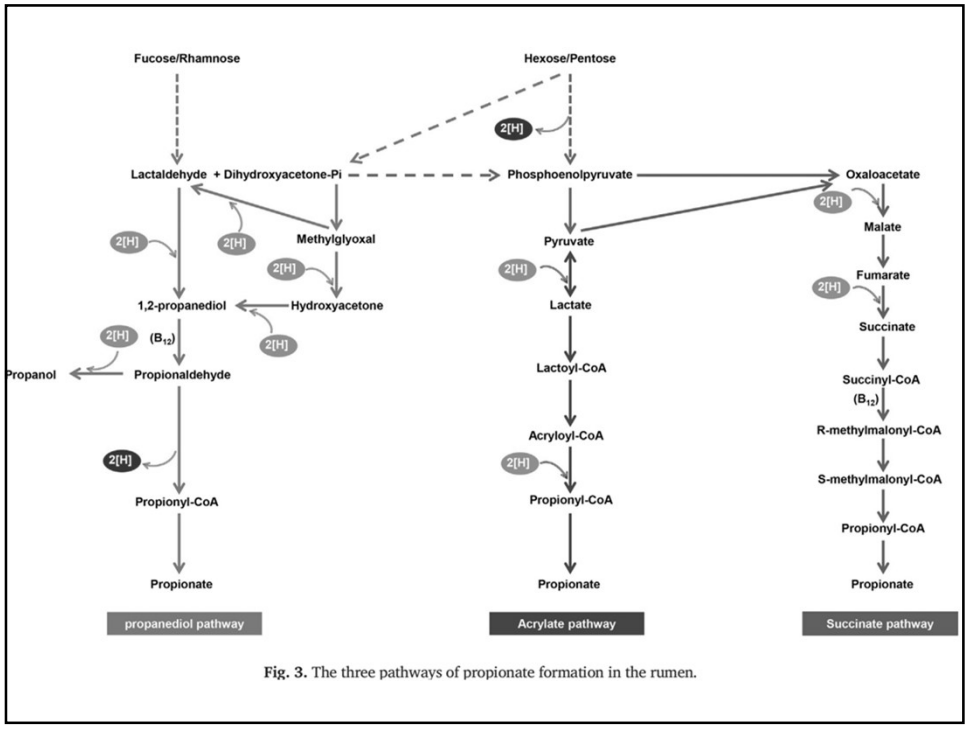



**Fig. 3.** The three pathways of propionate formation in the rumen.

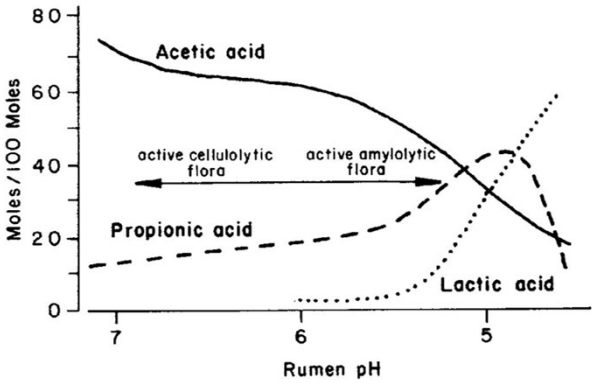
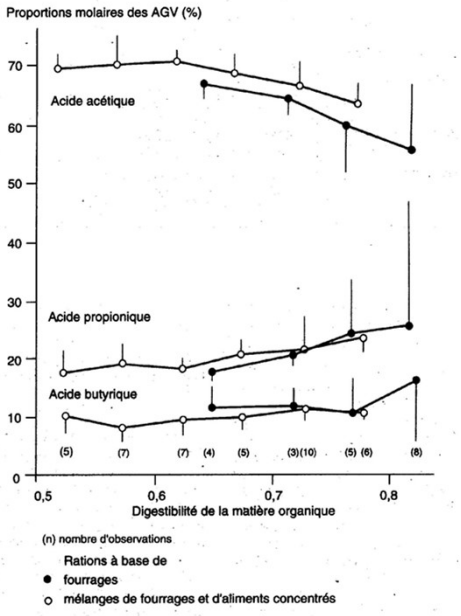



Figure 8-10. Relationship of ruminal pH to ruminal proportions of acetic, propionic and lactic acids. From Kaufmann et al (15).

**Relação entre a digestibilidade da MO e a proporção de AGV no rúmen.**



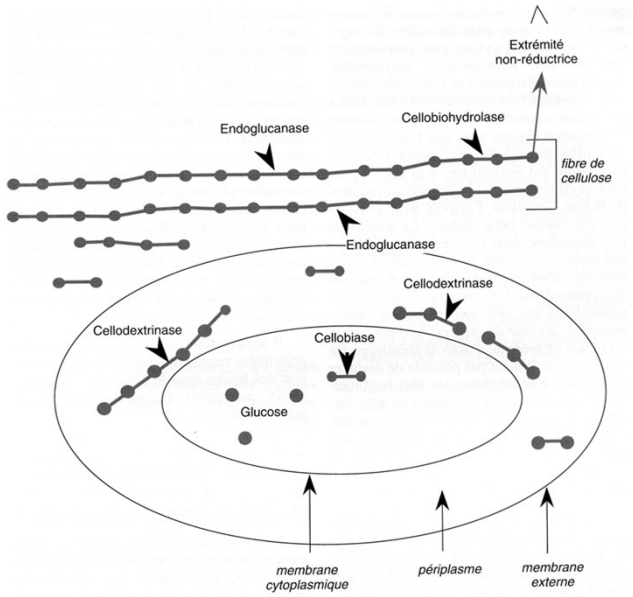




**Figure 8.4.** Modèle actuel de la dégradation de la cellulose par les enzymes caractérisées de *Fibrobacter succinogenes*.

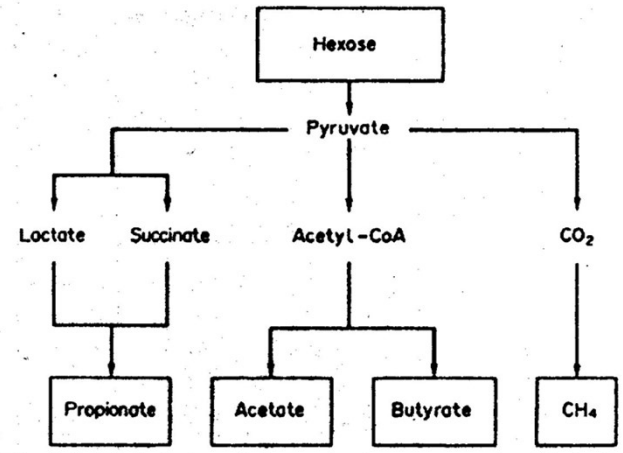



FIG. 1.5. Dissimilation of glucose in the rumen: a simplified scheme.

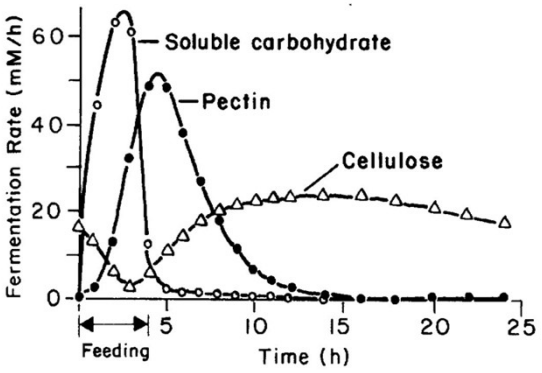
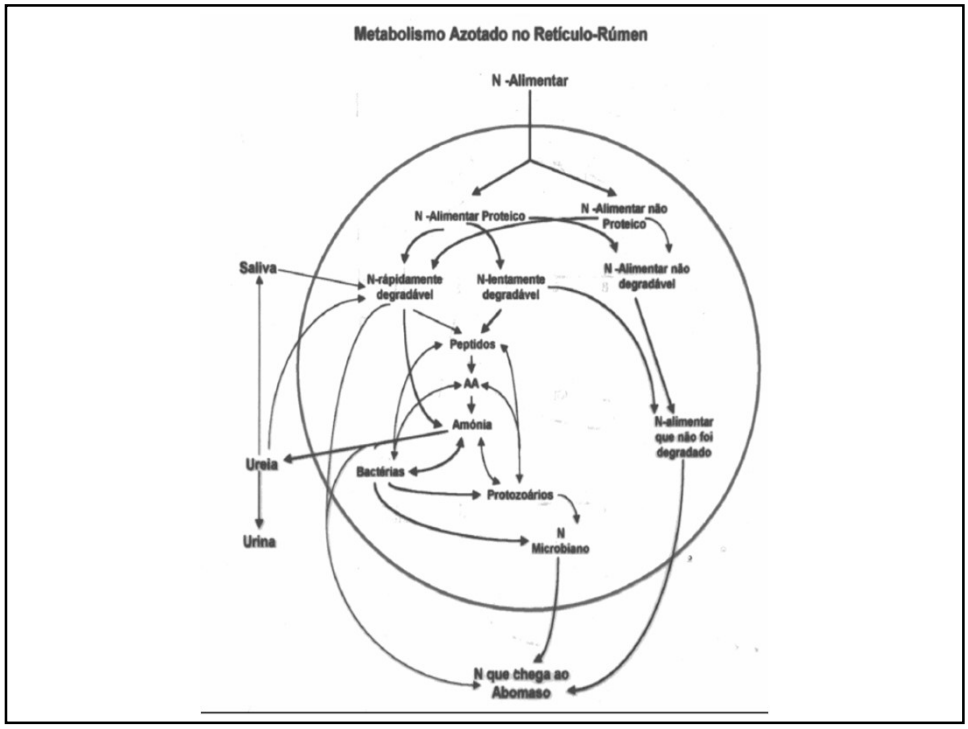
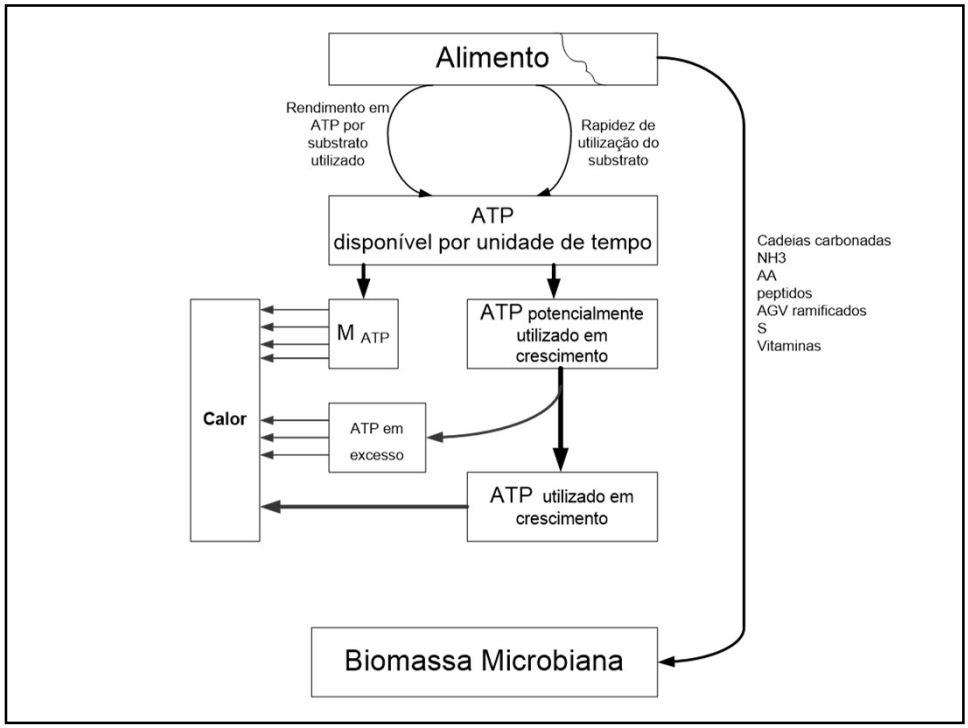



Figure 8-9. Fermentation of alfalfa components in the rumen. From Baldwin as cited by Smith and Oldham (28).


Metabolismo Azotado no Retículo-Rúmen
N -Alimentar
N -Alimentar Proteico
N -Alimentar não Proteico
Saliva
N-rápidamente degradável
N-lentamente degradável
N -Alimentar não degradável
Peptidos
AA
Amónia
N-alimentar que não foi degradado
Ureia
Bactérias
Protozoários
Urina
N Microbiano
N que chega ao Abomaso


Alimento
Rendimento em ATP por substrato utilizado
Rapidez de utilização do substrato
ATP disponível por unidade de tempo
Cadeias carbonadas
NH3
AA
peptidos
AGV ramificados
S
Vitaminas
M ATP
ATP potencialmente utilizado em crescimento
Calor
ATP em excesso
ATP utilizado em crescimento
Biomassa Microbiana

Obrigado pela atenção