Microbial ecology of the rumen: impact on nutrition and the environment

John Wallace
“We bring together extensive capabilities and expertise in nutritional research to pursue cutting edge science aimed at preventing disease and improving health through good nutrition. We aim to provide robust nutritional evidence to guide food and health policies.”
Microbial ecology of the rumen: impact on nutrition and the environment

- Introduction to the rumen and its microorganisms
- Impact of the rumen on nutrition
- Ruminants and the environment
- Ruminant products and human health
The rumen
Gut anatomy

PIG
- Stomach
- Jejunum
- Ileum

CATTLE AND SHEEP
- Stomach (Abomasum)
- Omasum
- Rumen
- Reticulum
- Jejunum
- Ileum
- Caecum
- Colon
- Caecum

Cattle and sheep
- Stomach (Abomasum)
- Omasum
- Rumen
- Reticulum
- Jejunum
- Ileum
- Caecum
- Colon
- Caecum
Rumen ciliate protozoa
Rumen anaerobic fungi
Rumen bacteria

1 μm
Proteobacteria

Cytophaga-Flexibacter-Bacteroides [CFB]

High bacterial diversity

Low G+C Gram positive

High G+C Gram positive, *Fibrobacter*, *Spirochaetes*, etc
Rumen methanogenic archaea
Metabolism in the rumen

- 10^9 - 10^{10} BACTERIA
- Up to 10^6 PROTOZOA
- ?? ANAEROBIC FUNGI
- 10^8 ARCHAEA per g digesta

Food → UNDIGESTED FOOD + MICROORGANISMS

VFA (ACETATE, PROPIONATE, BUTYRATE) → METHANE
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Fibre breakdown

*Ruminococcus flavefaciens*

*Fibrobacter succinogenes*
Protein metabolism

Food protein

Undegraded food protein + Microbial protein

Protein

Peptides

Amino acids

Ammonia

A

Ammonia

Protein metabolism

INEFFICIENCES

A Loss of N
B Microbial protein breakdown
C Amino acid imbalance
Breakdown of microbial protein

- Protein
- Peptides
- Amino acids
- Ammonia

- Up to 50% of microbial protein is recycled
- Defaunation increases microbial protein flow
  - Protozoa
  - -Protozoa

- Protozoa appear to cause >80% of bacterial protein breakdown

- Protein turnover (%)
  - + protozoa
  - - protozoa

- Incubation time (h)
  - 1 2 3 4
Rumen-up: influence on protozoal activity in vitro

Sample R038

Rate of degradation (%) vs. Incubation time (h)

Concentration (ppm)

Control
5000
3000
1500
1000
500

Lonicera japonica (Japanese honeysuckle)
Methane, ruminants and the environment
Methane, ruminants and the environment

• How much is methane a problem as a greenhouse gas?
• Is methane from ruminants really a major part of the problem?
• How does methane formation occur?
• How can we inhibit methane formation?
• Encapsulated fumaric acid, efficacy and commercial considerations
Greenhouse gases: CO$_2$
Methane as a greenhouse gas

$\text{CH}_4$ has a global warming potential ("radiative forcing") 21 times that of $\text{CO}_2$

Methane contributes approximately 18% to the overall global warming effect

US Environmental Protection Agency, 2000
Methane as a greenhouse gas

$t_\frac{1}{2}$ of CH$_4$ in atmosphere is 12 years

Dlugokencky et al., 2003
70% of global methane formation is due to man's activities
Therefore, 20% of global methane formation is due to ruminants.
Sources of atmospheric methane

And so 20% of the 18% = 3.6% of the total radiative forcing is caused by ruminants

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US Environmental Protection Agency, 2001
Ruminants, cars and methane

164 g CO₂/km at 19,000 km/year
= 164 × 19000 g CO₂/year
= 3 × 10^6 g CO₂/year

500 L CH₄/day
= 365 × 500 L/年
= 2 × 10^5 L/year
= 2 × 16/22 × 10^5 g/year
= 1.5 × 10^5 g/year
≈ 21 × 1.5 × 10^5 g CO₂/year
≈ 3 × 10^6 g CO₂/year
Ruminants, cars and methane
Ruminants, cars and methane
The New Zealand response

**Carbon tax**

As part of the Climate Change Policy Package, released in 2002, the government will be introducing a carbon tax in New Zealand from April 1, 2007. Hon. Pete Hodgson, Convener of the Ministerial Group on Climate Change, has announced that the carbon tax will be set at $15 per tonne of CO$_2$ and has released a consultation paper on the implementation of the tax.
Methane production in ruminants

5% → 95%
Methane production in ruminants

Fermentation

Protozoa, fungi, eubacteria

H₂ + CO₂

Archaea

CH₄
Inhibition of methane formation

- Halogenated hydrocarbons
- Other chemicals
- Ionophores
- Acetogenesis
- Immunisation
- Defaunation
- Natural plant extracts
- Organic acids
Decreasing methane emission using “organic acids”

Fermentation

[Organic acid + H₂] + CO₂

Propionic acid  CH₄
Organic acids

Oxaloacetate → Malate → Fumarate → Succinate → Propionate
Bakeshure 451

Bakeshure 451 – Consists of 85% fumaric acid and 15% partially hydrogenated soybean oil
Large scale feeding trial in Aberystwyth

Methane Production (L/d)

- Control
- Fumaric Acid
- Bakeshure 451

Feed Additive

Graph showing methane production levels for different feed additives.
Health implications of biohydrogenation in the rumen

LNA – linolenic acid
LA – linoleic acid

Saturated fatty acids

LNA
LA

C18:3 c9 c12 c15
C18:2 c9 c12

BIOHYDROGENATION

unsaturated
saturated
Health implications of biohydrogenation in the rumen

Helps Prevent Heart Disease

CLA

Helps Prevent Cancer

Stimulates Immune Response
To provide 10 g of CLA/day requires 3.6 kg cheese
Rumen Animal tissues

\[
\begin{align*}
\text{9} & \quad \text{12} \\
\text{linoleic acid} & \\
\text{conjugated linoleic acid} & \\
vaccenic acid & \\
stearic acid & \\
\end{align*}
\]
Effects on biohydrogenation of unsaturated fatty acids

- **C**<sup>cis</sup>**C**<sup>cis</sup>**C**<sup>cis</sup>
- **C**<sup>9</sup>**C**<sup>cis</sup>**C**<sup>cis</sup>**C**<sup>12</sup>
- linoleic acid
- **C**<sup>cis</sup>**C**<sup>trans</sup>**C**<sup>trans</sup>**C**
- conjugated linoleic acid
- **C**<sup>trans</sup>**C**<sup>trans</sup>**C**
- vaccenic acid
- **C**<sup>trans</sup>**C**<sup>trans</sup>**C**
- stearic acid

19 samples with activity against *B. proteoclasticus* but not *B. fibrisolvens*

- **Butyrivibrio fibrisolvens**
- **Butyrivibrio proteoclasticus**
Replacing antibiotics in animal feed

EC FP6
Promotion of Safe, Healthy Food

Chrysanthemum coronarium

- *C. coronarium* inhibits last step in biohydrogenation process
- *C. coronarium* increases PUFA and CLA content of milk

Vaccenic acid accumulates in the rumen

![Graph showing fatty acid concentration over time](image)
Inhibition of methane formation

- Defaunation
  - Decreases methane formation by 20%

Defaunation technically difficult
Adaptation will always be a problem