Rumen Fermentation
Effective Fiber
M. A. McGurie, Ph.D.

Volatile Fatty Acids (VFA)

- Produced from the fermentation of pyruvate
  - Rumen and hind gut
  - Types/ratios depends on diet
- 3 major VFAs
  - Acetate $\text{CH}_3\text{COOH}$
  - Propionate $\text{CH}_3\text{CH}_2\text{COOH}$
  - Butyrate $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$

Rumen Fermentation

- Glucose
- Pyruvate
- Hemicellulose
- Cellulose
- Starch
- Sugars
- Pectins
- Lactic
- Propionic
- Acetic
- Butyric
- Formic $\text{H}_2\text{CO}_2$
- Methane ($\text{CH}_4$)
Acetate

• Pyruvate + Pi + ADP → Acetate + ATP + H₂ + CO₂

• Cellulolytic bacteria
• Energy source for rumen epithelium and muscle
• Not utilized by liver

Acetate utilization

• Important as a precursor to de novo fatty acid synthesis
  – Adipose
  – Lactating mammary gland
• Oxidized via TCA
  – Activated to acetyl CoA
  – Used by skeletal muscle, kidneys, and heart for energy
  – Net gain of 10 ATP per mole of acetate

Acetate utilization

• Dependent upon
  – Energy balance
    • Generates CO₂ and H₂O (i.e., ATP) when in low energy balance
    • Used for fatty acid synthesis when animal is in high energy balance
  – Arterial concentration
    • Tissue uptake is directly related to rate of rumen fermentation [blood concentration]
Propionate

- Pyruvate + CoA + 4H⁺ → Propionate + H₂O
- Amylolytic bacteria
  - Utilized by rumen epithelium
    - Converted to lactate and pyruvate
- Important as a precursor for gluconeogenesis

Hepatic propionate metabolism

Butyrate

- Pyruvate + CoA →
  Acetyl-CoA + H₂ + CO₂
- 2 Acetyl-CoA + 4H⁺ →
  Butyrate + H₂O + CoA
- Metabolized by rumen epithelium to ketone bodies (acetoacetate, β-hydroxybutyrate)
  - Later metabolized in liver
- Net ATP production is 25 per mole
**Ruminal VFA absorption**

<table>
<thead>
<tr>
<th>VFA</th>
<th>Rumen lumen</th>
<th>Rumen wall</th>
<th>Portal vein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetate</td>
<td>70</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>Propionate</td>
<td>20</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Butyrate</td>
<td>10</td>
<td>9</td>
<td>1</td>
</tr>
</tbody>
</table>

Values are relative flux rates.

**Hepatic metabolism of VFA**

<table>
<thead>
<tr>
<th>VFA</th>
<th>Rumen</th>
<th>Portal vein</th>
<th>Liver</th>
<th>Peripheral blood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetate</td>
<td>70</td>
<td>50</td>
<td>Acetate</td>
<td>Acetate</td>
</tr>
<tr>
<td>Propionate</td>
<td>20</td>
<td>10</td>
<td>Glucose</td>
<td>Glucose</td>
</tr>
<tr>
<td>Butyrate</td>
<td>10</td>
<td>1</td>
<td>3-OH butyrate</td>
<td>3-hydroxy Butyrate (BHBA)</td>
</tr>
</tbody>
</table>

**Fermentation in the Rumen**

*Convert all available carbohydrates and some amino acids to volatile fatty acids (VFA)*

- Cellulose
- Hemicellulose
- Pectin
- Starch
- Sugars

Bacterial fermentation

VFA, lactate and methane

Concentration of VFA in rumen = 50 to 125 μM/ml
Fermentation in the Rumen

<table>
<thead>
<tr>
<th>Diet</th>
<th>Acetate</th>
<th>Propionate</th>
<th>Butyrate</th>
<th>Ratio Acetate:Propionate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hay</td>
<td>65</td>
<td>20</td>
<td>12</td>
<td>3:1</td>
</tr>
<tr>
<td>Grain</td>
<td>40</td>
<td>37</td>
<td>20</td>
<td>1:1</td>
</tr>
</tbody>
</table>

Amino Acid Fermentation in the Rumen

Deamination required
- Removal of the amino (NH$_2$) group
- Ammonia produced

Fermentation to
- Acetate
- Propionate
- Branched chain volatile fatty acids
  - Isovalerate
  - Isobutyrate

Sources of energy leaving rumen:

- VFA 70%
- Microbial cells 10%
- Digestible unfermented feed 20%

*No glucose available for the ruminant*
Evaluating effective fiber and rumen health

Some slides adapted from Dairy Nutrition & Management (ANSCI 200/492), University of Illinois at Urbana-Champaign, Dr. Mike Hutjens. Some pictures from Dr. Mary Beth Hall, USDA-ARS.

Penn State Separator Box

Measure eNDF

Also available with 4 screens
### Penn State Separator

<table>
<thead>
<tr>
<th></th>
<th>Top</th>
<th>Middle</th>
<th>Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Silage (1/4)</td>
<td>&lt; 5</td>
<td>&gt; 50</td>
<td>&lt; 50</td>
</tr>
<tr>
<td>Corn Silage (1/2)</td>
<td>&lt; 5</td>
<td>&gt; 70</td>
<td>&lt; 30</td>
</tr>
<tr>
<td>Haylage</td>
<td>&gt; 20</td>
<td>&gt; 40</td>
<td>&lt; 40</td>
</tr>
<tr>
<td>TMR</td>
<td>&gt; 10</td>
<td>&gt; 30</td>
<td>&lt; 50</td>
</tr>
</tbody>
</table>

http://www.das.psu.edu/dairynutrition/documents/das0242.pdf

### Applying the Results

**Penn State Box**

Effective NDF = 100 - (% in bottom box)

Example:

Alfalfa Haylage with 52% in the bottom box
Effective NDF = 100 - 52
= 48%

### FIELD TOOLS

- Milk yield changes
- Milk component changes
- Signs of acidosis
  - Laminitis, sore feet
- Manure scores
- Free choice buffer use
- Grain in manure
Subclinical Ruminal Acidosis

- Rumen pH
- Rumen motility
- Rumination
- Variation in daily intake
- Feces variable
  - Firm ↔ diarrhea
  - Undigested fiber & grain
  - Gas bubbles
  - Mucin/fibrin casts
- Fecal particle size
- Feed efficiency
- Production

Rapidly fermented CHO intake
- Total & effective NDF intake
- Reduced rumen mat
- Rumination & buffering with saliva
- Ruminal acid concentration
- Ruminal pH
- Feed retention time in rumen
- Ruminal fiber and feed digestion

Feed efficiency
Production
A shift in the site of digestion changes nutrient supply & causes some of the symptoms of ruminal acidosis.
Effective fiber must be eaten to be effective.