Sugars: 6 Carbon

Sugars

Glucose / Dextrose
Monosaccharides Simple sugars
Fructose
Sucrose
Disaccharides
Lactose

4/19/17
U.S. Dairy Forage Research Center
Sugars in Feed

% of Dry Matter

- Suc+Glc+Fru
- Lactose

SBM, Beet pulp, Alfalfa, Temp. Grass, Whey permeate, Molasses
WSC includes more than mono- & di-saccharides.

Best measure of sugars in molasses is total sugars as invert.
Analyzing Carbohydrates

Plant Carbohydrates

Cell Contents
- Organic Acids
  - Simple sugars, sucrose, lactose
- Fructans
- Starch
- Pectic Substances
  - Mixed linkage β-glucans

Cell Wall
- Hemicellulose
- Cellulose
- Lignin

Water-soluble
- NFC
- Starch

Non-Fiber Carbohydrates (NFC)
ADF
NDF
WSC, Soluble carbohydrates

% of Dry Matter

WSC: Perfect?
Sugars: What makes them tick?

- How much is there?
- What do we feed with them?
- Rate of use & fates
- What else do the microbes do?
- What feed is it in?
### Equivalence of NFC

<table>
<thead>
<tr>
<th></th>
<th>Glucose</th>
<th>Sucrose</th>
<th>Starch</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 lb DM</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Hydrolyzed Monomers</td>
<td>1.00</td>
<td>1.05</td>
<td>1.11</td>
</tr>
<tr>
<td>% of Starch</td>
<td>90%</td>
<td>95%</td>
<td>100%</td>
</tr>
</tbody>
</table>

*U.S. Dairy Forage Research Center*
Microbial Protein: Glucose

- More rapid fermentation >> more rapid growth >> greater growth (dilution of maintenance)
- Affected by protein source

Hall, 2016
Hristov et al., 2005
Microbial Protein: Lactose

- More rapid fermentation >> more rapid growth >> greater growth (dilution of maintenance)
- Affected by protein source

Hall, 2016
Increases in protein supply gave increased microbial YIELDS at each amount of carbohydrate in vitro.

Figure 2. Microbial yields (µg RNA/mg carbohydrate added) after 6-h incubations with varying concentrations of amino acids plus peptides at different carbohydrate concentrations (Experiment 4). Ammonia as sole N source (X, Y =
Sugars: Use vs. Fermentation

Readily Available Carbohydrates = Organic acids + Microbes + Gas

- glucose
- fructose
- sucrose
- lactose
- raffinose
- fructan
- starch

Fermentation tubes

+glucose -glucose
Glycogen Production

- Like starch
- 1 ATP per glucose added, -25 to 33% of ATP yield
- More RDP, less glycogen… type of RDP?
- More rapidly available >> more glycogen

Glucose + Protein Sources

Glucose vs. Lactose
Protein and Rumen pH

NFC x RDP for Sugar v Citrus $P = 0.02$

Hall et al., 2010
Glycogen: Pros & Cons

**More Glycogen**
- Less energy for microbial growth
- Slows fermentation
- Dampen pH drops
- Another SI “starch” source?

**Less Glycogen…?**
- Make more microbes
- Faster fermentation >> more lactic acid
- Greater ruminal digestion

Sugars vs Starch?

Counotte and Prins, 1981
Branco et al., 1999
NFC & RDP and NDF Digestibility

NDF digested %

0.031% of BW as RDP

- Ctrl:
- Starch:
- Glucose:
- Fructose:
- Sucrose:

0.122% of BW as RDP

- Ctrl:
- Starch:
- Glucose:
- Fructose:
- Sucrose:

NFC at 0.3% of BW

Heldt et al., 1999
Piwonka and Firkins, 1996
Effect on Milk Fat

Biohydrogenation

- Some glucose-utilizing microbes biohydrogenate fat
- Trans-10 isomer of C18:1 associated with milk fat depression

<table>
<thead>
<tr>
<th></th>
<th>Low sugar</th>
<th>High Sugar</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM Intake, lb</td>
<td>37.9</td>
<td>40.3</td>
</tr>
<tr>
<td>Rumen pH</td>
<td>6.06</td>
<td>6.21</td>
</tr>
<tr>
<td>Butyrate, mol%</td>
<td>12.2</td>
<td>12.8</td>
</tr>
<tr>
<td>Milk, lb</td>
<td>73.4</td>
<td>75.8</td>
</tr>
<tr>
<td>Fat lb/%</td>
<td>2.98 / 4.21</td>
<td>3.17 / 4.27</td>
</tr>
<tr>
<td>C18:1 trans % of milk fatty acids</td>
<td>3.14</td>
<td>2.72</td>
</tr>
</tbody>
</table>

In the first 4 weeks of lactation, substituted 4.7% sucrose for cracked corn grain. Barley silage, alfalfa hay. ~20% CP, 50% forage, 33-34% NDF, 20.6 and 18.5% starch.

McKain et al., 2010
Penner and Oba, 2009
Effect on Milk Fat

Butyrate

- More butyrate from sugars than starch
- Increase milk fat?
- Butyrate = 30% of the fatty acids in the sn-3 position on milk triglycerides

<table>
<thead>
<tr>
<th>Molar % of Butyrate</th>
<th>Starch/Ctrl</th>
<th>Sucrose/Lactose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strobel &amp; Russell, 1986</td>
<td>8.2</td>
<td>9.5</td>
</tr>
<tr>
<td>DeFrain et al., 2004</td>
<td>13.9</td>
<td>16.3</td>
</tr>
<tr>
<td>Charbonneau et al., 2006</td>
<td>8.2</td>
<td>11.4</td>
</tr>
<tr>
<td>Hall et al., 2010</td>
<td>9.5</td>
<td>12</td>
</tr>
</tbody>
</table>

Rook and Balch, 1961
Rook et al., 1965
Jensen, 2002
## Sucrose vs. Starch

<table>
<thead>
<tr>
<th>Sucrose:Starch (% Diet DM)</th>
<th>0:7.5</th>
<th>2.5:5.0</th>
<th>5.0:2.5</th>
<th>7.5:0</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM intake</td>
<td>54.0</td>
<td>56.4</td>
<td>57.3</td>
<td>57.3</td>
</tr>
<tr>
<td>Milk, lb</td>
<td>85.8</td>
<td>89.1</td>
<td>88.2</td>
<td>86.9</td>
</tr>
<tr>
<td>Fat, lb</td>
<td>3.24</td>
<td>3.37</td>
<td>3.64</td>
<td>3.57</td>
</tr>
<tr>
<td>Protein, lb</td>
<td>2.73</td>
<td>2.82</td>
<td>2.84</td>
<td>2.82</td>
</tr>
<tr>
<td>Rumen pH</td>
<td>6.19</td>
<td>6.16</td>
<td>6.19</td>
<td>6.21</td>
</tr>
<tr>
<td>Milk/DMI</td>
<td>1.60</td>
<td>1.58</td>
<td>1.54</td>
<td>1.52</td>
</tr>
<tr>
<td>MN/IN</td>
<td>0.31</td>
<td>0.29</td>
<td>0.29</td>
<td>0.30</td>
</tr>
<tr>
<td>FPCM/DMI</td>
<td>1.64</td>
<td>1.63</td>
<td>1.66</td>
<td>1.64</td>
</tr>
</tbody>
</table>

*P* = <0.05, *P* < 0.10

Alfalfa Silage: 40.0%, Corn Silage: 20.0%, HMSC: 20.5%  
Broderick et al., 2002
## Whey Permeate vs. Starch

<table>
<thead>
<tr>
<th></th>
<th>Ctrl</th>
<th>Gr. Corn</th>
<th>GC+St</th>
<th>GC+W</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM intake&lt;sup&gt;T&lt;/sup&gt;</td>
<td>50.0</td>
<td>53.6</td>
<td>53.8</td>
<td>56.7</td>
</tr>
<tr>
<td>Milk, lb&lt;sup&gt;T&lt;/sup&gt;</td>
<td>75.0</td>
<td>82.4</td>
<td>82.9</td>
<td>78.9</td>
</tr>
<tr>
<td>Fat, lb&lt;sup&gt;%&lt;/sup&gt;</td>
<td>2.82</td>
<td>2.89</td>
<td>2.82</td>
<td>3.02</td>
</tr>
<tr>
<td>Protein, lb&lt;sup&gt;T&lt;/sup&gt;</td>
<td>2.38</td>
<td>2.72</td>
<td>2.72</td>
<td>2.59</td>
</tr>
<tr>
<td>Rumen pH</td>
<td>6.50</td>
<td>6.41</td>
<td>6.41</td>
<td>6.51</td>
</tr>
<tr>
<td>NEL Milk/DMI&lt;sup&gt;%&lt;/sup&gt;</td>
<td>67.75</td>
<td>70.38</td>
<td>67.88</td>
<td>70.13</td>
</tr>
<tr>
<td>MN/IN&lt;sup&gt;%&lt;/sup&gt;</td>
<td>24.8</td>
<td>27.9</td>
<td>28.4</td>
<td>24.9</td>
</tr>
</tbody>
</table>

<sup>T</sup> P=<0.05,

Alfalfa Silage: 45%, Gr. Corn: 35-47%, WP or St: 11%

Charbonneau et al. 2006
How much sugar can we feed?
Taking This To The Farm

- All sugars are not the same: lactose vs…
- Protein affects how microbes handle it
- Protein production: sugars vs. starch
- May increase fat test… but when?
- Less negative effect on rumen pH
- Not “fast starch”
Questions......

- How much of what sugars can we feed?
- What’s optimal in what rations?
- How do sugar and fat feeding interact?
- How does sugar affect fat test?
- Feeding RDP & sugars?
- Sugars are in feeds....
Questions?

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www.ars.usda.gov/mwa/madison/dfrc