Primary Factors Contributing to Corn Silage Digestibility

• High starch with high starch digestion

• High fiber digestion (NDF-D)

• Every increase 1 unit increase in NDF-D has the potential to increase ~ 0.4 lb DM intake and about 0.5 lb milk

Oba and Allen, 1997
Brown Midrib Corn Mutants Have Low Lignin => High NDF-D

• Four natural mutations identified in the 1930-40’s in dent corn bm1, bm2, bm3, bm4

• Low in lignin therefore higher fiber digestion

• Brown to red pigment in the leaf midrib, rind and pith

Distribution of in vitro NDF digestibility at 30 h between conventional and BMR corn silage samples (CVAS, Oct. 2012 – Apr. 2013)

Conventional
• n = 18,270
• Ave. = 59.4% ± 4.01

BMR
• n = 1,585
• Ave. = 68.4% ± 4.23

Nestor, 2013
How Does BMR Compare to Normal Hybrids?

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>BMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM, % of as fed</td>
<td>33.5</td>
<td>32.5</td>
</tr>
<tr>
<td>Starch, % of DM</td>
<td>30.5</td>
<td>29.9</td>
</tr>
<tr>
<td>NDF, % of DM</td>
<td>42.0</td>
<td>40.9</td>
</tr>
<tr>
<td>ivNDFD, % of NDF</td>
<td>46.1</td>
<td>57.6</td>
</tr>
</tbody>
</table>

In vitro NDF digestibility measured after in vitro fermentation for 30 h except for trial of Weiss and Wyatt, 2006 where a 48 h determination was performed.

Gencoglu, Shaver and Lauer, UW Madison

Effect of BMR on Production – UW Meta Analysis

<table>
<thead>
<tr>
<th>Item</th>
<th>Normal</th>
<th>BMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMI, kg/d</td>
<td>24.2</td>
<td>25.4</td>
</tr>
<tr>
<td>Milk, kg/d</td>
<td>37.7 (83 lb)</td>
<td>39.4 (87 lb)</td>
</tr>
<tr>
<td>Fat, %</td>
<td>3.67</td>
<td>3.59</td>
</tr>
</tbody>
</table>

Results are least-square means from meta-analysis (St. Pierre, 2001) performed on data from 11 trials with 17 treatment comparisons published in the Journal of Dairy Science since 1999; Gencoglu, Shaver and Lauer, UW Madison
## Normal Corn Hybrids and NDFD

- Company selections
- Leafy
- High sugar
- Soft pith

- Research data is inconclusive

- **True selections/evaluations vs random screenings**

- Multi year evaluations vs 1-2 yr evaluations

- Is unbiased information available?

---

### 110-DAY HYBRID TRIAL AVERAGE

<table>
<thead>
<tr>
<th>Variety</th>
<th>Brand</th>
<th>YR</th>
<th>Yield</th>
<th>BU/AC</th>
<th>Sugar</th>
<th>Protein</th>
<th>Breakage</th>
<th>DWGS</th>
<th>flags</th>
</tr>
</thead>
<tbody>
<tr>
<td>NK Brand N70J-3011A CB,LL,RR,RW-wo</td>
<td>11.1</td>
<td>3170</td>
<td>35200</td>
<td>65.6</td>
<td>61</td>
<td>29</td>
<td>11.1</td>
<td>10.7</td>
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<tr>
<td>Legacy Seeds L750</td>
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<td>3300</td>
<td>36600</td>
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<td>62</td>
<td>30</td>
<td>11.1</td>
<td>10.8</td>
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<tr>
<td>DuPont Pioneer P1468AM1</td>
<td>11.0</td>
<td>3200</td>
<td>36600</td>
<td>65.6</td>
<td>63</td>
<td>28</td>
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<td></td>
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<tr>
<td>Maize Quest M28183</td>
<td>9.4</td>
<td>3440</td>
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<td></td>
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<tr>
<td>Monsanto FS 3101XBB</td>
<td>10.8</td>
<td>3170</td>
<td>35300</td>
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<td>62</td>
<td>28</td>
<td>11.3</td>
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<tr>
<td>Golden Harvest GS251-3011A</td>
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<td>35800</td>
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<tr>
<td>Syngenta DS1571RA</td>
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<td>35600</td>
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<td>65</td>
<td>28</td>
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<td></td>
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<tr>
<td>Nutrien/NyCo Genetics SF-81</td>
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<td>3200</td>
<td>36400</td>
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<td>63</td>
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<tr>
<td>Syngenta DS773RA</td>
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<tr>
<td>AgriGold A6538STX</td>
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<td>3150</td>
<td>35600</td>
<td>67.3</td>
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<td>28</td>
<td>11.3</td>
<td>10.5</td>
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</table>

### 115-DAY HYBRID TRIAL AVERAGE

<table>
<thead>
<tr>
<th>Variety</th>
<th>Brand</th>
<th>YR</th>
<th>Yield</th>
<th>BU/AC</th>
<th>Sugar</th>
<th>Protein</th>
<th>Breakage</th>
<th>DWGS</th>
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<tbody>
<tr>
<td>DuPont Pioneer P1339AM1</td>
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<td>62</td>
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<td>11.1</td>
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<tr>
<td>Masters Choice M05470</td>
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<td>3120</td>
<td>34000</td>
<td>67.4</td>
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<td>11.1</td>
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<tr>
<td>Monsanto FS 3101XBB</td>
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<td>3140</td>
<td>34000</td>
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<td>62</td>
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<tr>
<td>Syngenta MC7563</td>
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<td>35000</td>
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<tr>
<td>Nutrien/NyCo Genetics SF-317</td>
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<td>36000</td>
<td>67.9</td>
<td>64</td>
<td>26</td>
<td>11.1</td>
<td>11.1</td>
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<tr>
<td>Mycogen TM40R72</td>
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<td>36000</td>
<td>68.1</td>
<td>63</td>
<td>27</td>
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<tr>
<td>AgriGold A6559STXRIB</td>
<td>10.9</td>
<td>3080</td>
<td>33600</td>
<td>67.5</td>
<td>62</td>
<td>26</td>
<td>11.8</td>
<td>11.0</td>
<td></td>
</tr>
</tbody>
</table>
Accessibility of Starch in Corn Silage

• Starch must be accessible by bacteria in the rumen

• Factors that limit the access to starch
  - Pericarp
  - Surface area
  - Protein/starch matrix

Fecal Starch and Digestibility

- 4.5% fecal starch ~ 90% starch digestibility
- 1% unit decrease in fecal starch ~ 1 pound more milk
- Range in starch: 2.3 - 22.4%

(Ferguson, 2006)
Starch Digestibility is Positively Correlated with Milk Yield
Firkins et al., 2001

![Graph showing correlation between Starch Digestibility and Milk Yield.]

- **Equation:** \( y = 0.1285x + 20.582 \)
- **R²:** 0.7032

**Mechanical Processing Effects on Corn Silage**
*(34% DM - BMR)*

<table>
<thead>
<tr>
<th>Item</th>
<th>Unprocessed</th>
<th>Processed</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM intake, lb/d</td>
<td>52.7</td>
<td>56.8*</td>
</tr>
<tr>
<td>Milk, lb/d</td>
<td>93.4</td>
<td>98.0*</td>
</tr>
</tbody>
</table>

Ebling and Kung, 2004
Shredlage - Potential for High Level of Kernel Processing With Long Effective Fiber (potentially even in relatively high DM samples)

Shredlage

Conventional Kernel Processed

Photos provided by Kevin Shinners, UW Madison, BSE

Kernel Processing Score

Samples obtained during feed-out from the silo bags

<table>
<thead>
<tr>
<th></th>
<th>Shredlage</th>
<th>KP</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Starch Passing 4.75 mm Sieve</td>
<td>75.0% ± 3.3</td>
<td>60.3% ± 3.9</td>
</tr>
</tbody>
</table>

Shaver, 2013
### Shredlage® KP P

| Rumen StarchD, % of Starch | 88.3% | 76.0% | 0.05 |

<table>
<thead>
<tr>
<th>Crop Year</th>
<th>Number</th>
<th>Average</th>
<th>Percent Optimum</th>
<th>Percent Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>97</td>
<td>52.8</td>
<td>8.2</td>
<td>43.3</td>
</tr>
<tr>
<td>2007</td>
<td>272</td>
<td>52.3</td>
<td>9.2</td>
<td>37.9</td>
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<tr>
<td>2008</td>
<td>250</td>
<td>54.6</td>
<td>5.2</td>
<td>34.8</td>
</tr>
<tr>
<td>2009</td>
<td>244</td>
<td>51.1</td>
<td>6.1</td>
<td>48.0</td>
</tr>
<tr>
<td>2010</td>
<td>373</td>
<td>51.4</td>
<td>5.9</td>
<td>43.4</td>
</tr>
<tr>
<td>2011</td>
<td>726</td>
<td>55.5</td>
<td>12.3</td>
<td>33.1</td>
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<tr>
<td>2012</td>
<td>871</td>
<td>60.8</td>
<td>14.8</td>
<td>19.9</td>
</tr>
<tr>
<td>2013</td>
<td>2658</td>
<td>64.6</td>
<td>36.0</td>
<td>12.9</td>
</tr>
<tr>
<td>2014</td>
<td>322</td>
<td>61.8</td>
<td>24.2</td>
<td>9.0</td>
</tr>
</tbody>
</table>

*Adapted from slide provided by Ralph Ward of CVAS*
Assuming Access to Corn Starch is Not Limiting, What Options are There to Improve Ruminal Starch-D?

• Allow natural proteolytic mechanisms during ensiling to occur which increase starch-D

• Use enzymes to accelerate this process
  – Amylases
  – Proteases

Reports of Increase in Ruminal Starch-D in Corn Silages and HMC with Ensiling

HMC
• Philippeau and Michalet-Doreau, 1998 (short period of ensiling)
• Allen et al., 2003 (moderate)
• Benton et al., 2005 (long)

Corn silage
• Jurjanz and Monteils, 2005 (short)
• Newbold et al., 2006 (long)
• Hallada et al., 2008 (long)
• Snyder, 2011 (long)
• Der Bedrosian et al., 2012 (long)
**In Situ Ruminal DM Disappearance for HMC is Influenced by Length of Ensiling (long term) and Moisture**

![Graph showing IVDMD (% vs Days of ensiling)](image)

In Situ Ruminal DM Disappearance for HMC is Influenced by Length of Ensiling (long term) and Moisture

**Degradation of Endosperm Proteins (Same Hybrid)**

<table>
<thead>
<tr>
<th>Snaplage</th>
<th>HMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia = 6.0% of CP</td>
<td>Ammonia = 1.8% of CP</td>
</tr>
<tr>
<td>Kernel MPS = 1456 µ</td>
<td>MPS = 1335 µ</td>
</tr>
</tbody>
</table>

**Degradation of Endosperm Proteins (Same Hybrid)**

- **Snaplage**: 0% translucent
- **HMC**: 80% translucent
Proteolysis of the Protein/Starch Matrix During Storage Results in Increases in Starch-D

Hoffman et al., 2011

IVStarchD Increased by Length of Ensiling in HMC (summary of commercial lab data)

Ferraretto and Shaver, 2013
Prolonged Ensiling Improves In Vitro Starch Digestion of Corn Silage

~22% starch

Norm – 32% DM

BMR – 32% DM

~32% starch

Norm – 42% DM

BMR – 42% DM

Days of Storage

2012 Der Bedrosian et al.

Soluble Protein and Ammonia-N Continue to Increase with Prolonged Ensiling

2012 Der Bedrosian et al.
Correlations Between Markers of Proteolysis and Starch-D

Soluble Protein, % of CP (Krishnamoorthy, et al., 1983)
NH3-N, % of total N, (NH3-N probe, Kjedahl, NIRS, etc)

A

B

$R^2 = 0.61$

$P = 0.001$

$R^2 = 0.55$

$P = 0.001$
Correlation Between Protein Degradation and Starch-D in Corn Silages

Effect of Days of Ensiling on Starch Digestion in Corn Silage
Issues With Storing Silages for Prolonged Times In Order Achieve High Potential Ruminal Starch-D

- Resources (land, storage capacity?)
- Cost of prolonged storage?
- Challenges
  - keeping silage from spoilage during storage
  - plastic integrity

Assuming Access to Corn Starch is Not Limiting, What Options are There to Improve Ruminal Starch-D?

- Allow natural proteolytic mechanisms during ensiling to occur which increase starch-D

- Use enzymes to accelerate this process
  - Amylases
  - Proteases
## Adding Amylases at Ensiling –
*Spoelstra et al., 1992*

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Amylase</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM, %</td>
<td>38</td>
<td>35</td>
</tr>
<tr>
<td>Starch, %</td>
<td>31</td>
<td>24</td>
</tr>
<tr>
<td>Sugars, %</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Lactic acid, %</td>
<td>6.2</td>
<td>7.3</td>
</tr>
<tr>
<td>Acetic acid, %</td>
<td>1.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Ethanol, %</td>
<td>0.7</td>
<td>5.0</td>
</tr>
<tr>
<td>Yeasts, log cfu/g</td>
<td>&lt;2</td>
<td>5</td>
</tr>
<tr>
<td>Aerobic stability, h</td>
<td>148</td>
<td>76</td>
</tr>
</tbody>
</table>

## Proteases

- Biofuels industry to yield higher growth of yeasts and more ethanol (usually acid proteases)
- Feed additive (usually neutral or alkaline proteases)—some research showing improved in vitro starch D
  - Lichtenwalner et al., 1978
  - McAlister et al., 1993
  - DePeters et al., 2007
- Historically not used as a silage additive because proteolysis is already excessive
Description of Protease Experiments at UD

- Supplied by
  - AB Vista, UK
  - Novozymes, Denmark
- Acid proteases
- Low pH optimum of ~3.5
- No carbohydrate activities
- Silages stored at ~22°C unless otherwise stated

Activity for AB Vista Protease

Windle and Kung, University of Delaware
% activity relative to 100% at pH 3.6

abcd $P < 0.05$
**Effect of Protease Dose on 7 h \textit{in vitro} Digestibility of Starch of Corn Silage**

Windle and Kung, University of Delaware

**Effect of a Protease on Indicators of Proteolysis in HMC**

Kung, et al., 2014 JDS
Effect of a Protease on In Vitro Ruminal Starch-D of HMC

Kung, et al., 2014 JDS

Effect of a Protease on Prolamin Protein Analysis

Kung, et al., 2014 JDS
Other Options to Improve Ruminal Starch D?

• Proteases + amylases?
• CS hybrid selection? (Floury, opaque)
• Designer inoculants

What Can We Do Today to Maximize Starch D From CS and HMC?

• Avoid harvesting dry (mature) CS
• Process adequately
• Feed less mature (wetter) CS first, store dry (mature) CS longer
• Can’t win the battle.....post ensiling processing?
Summary

BMR is the primary technology to increase corn silage NDFD

Selection or inoculant technologies to alter NDFD in normal corn silage hybrids are less defined

Intensity and duration of fermentation is the primary mechanism that increases corn silage starch digestibility. LEARN TO FOLLOW CP FRACTIONS!

Corn silage processing increases starch digestibility and milk yield.

Factors that influence starch digestibility in cows are now well defined and technologies such as enzymes, custom designed inoculants and or designer hybrids are all possible.