Starch, from corn grain & silage, utilization by cattle

Randy Shaver, Ph.D., PAS, Dipl. ACAS
Extension Dairy Nutritionist

- Starch is broad term
  - Amylose
  - Amylopectin
Starch structure

Normal Dent Corn
• 72:28 Amylopectin:Amylose

Waxy Mutant Corn
• 100% Amylopectin

Primary Factors Influencing Starch Digestibility in Corn Grain

- Processing
  i.e. Particle size; Steam Treatment

- Harvest/Storage
  i.e. Dry vs. HMC DM of HM/Maturity; Fermentation Time

- Endosperm Type
  i.e. Prolamin; Prolamin-starch matrix; Hardness

Adapted from Pat Hoffman, UW Madison Dairy Sci. Dept.
Table 4. Impact of various processing techniques on grain and its digestion.

<table>
<thead>
<tr>
<th>Grain treatment/processing</th>
<th>Disrupts pericarp or exposes endosperm</th>
<th>Reduces particle size</th>
<th>Disrupts endosperm matrix</th>
<th>Disrupts starch granules</th>
<th>Increases fermentation rate</th>
<th>Increases intestinal digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry rolling</td>
<td>+++</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Grinding</td>
<td>+++</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Steam flaking</td>
<td>+++</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+++</td>
<td>+</td>
</tr>
<tr>
<td>Extrusion</td>
<td>+++</td>
<td>-</td>
<td>++</td>
<td>+</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Pelleting</td>
<td>+++</td>
<td>-</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>++</td>
</tr>
<tr>
<td>Ensiling</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>-</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Micronization</td>
<td>+</td>
<td>+</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>++</td>
</tr>
<tr>
<td>Popping</td>
<td>++</td>
<td>-</td>
<td>++</td>
<td>?</td>
<td>?</td>
<td>++</td>
</tr>
<tr>
<td>Protease</td>
<td>-</td>
<td>-</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

Source: Dr. Fred Owens, Conf. Proc. paper, UMN web site

Whole-Plant Corn Silage

- Grain ~40-45% of WPDM
  - Avg. 32% starch in WPDM
  - Variable grain:stover
- Stover ~55-60% of WPDM
  - Avg. 41% NDF in WPDM
  - Variable stover:grain

- 80 to 98% StarchD
  - Processing, particle size
  - Fermentation
  - Maturity
  - Endosperm properties
  - Additives (exp.)

- 40 to 70% TVNDF
  - Lignin/NDF
    - Hybrid Type
    - Environment: G × E
    - Maturity
    - Cutting height
    - Additives (exp.)

Variable pNDF as per chop length

Adapted from Joe Lauer, UW Madison Agronomy Dept.
Ruminant Starch Digestion

Rumen

Microbial Fermentation
- VFA
- Propionate
- Glucose via liver
- Microbial Protein

Small Intestine

Digestion (Enzymatic)
- Glucose

Hind Gut

Microbial Fermentation
- VFA

Starch Digestibility of Corn in Feedlot Cattle

Source: Dr. Fred Owens, Conf. Proc., UMN web post, 2018

<table>
<thead>
<tr>
<th></th>
<th>Whole</th>
<th>Dry Rolled</th>
<th>High Moisture</th>
<th>Steam Flaked</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Diet Observations</td>
<td>6</td>
<td>42</td>
<td>8</td>
<td>94</td>
</tr>
<tr>
<td>% of Starch Intake</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ruminal</td>
<td>68</td>
<td>64</td>
<td>87</td>
<td>84</td>
</tr>
<tr>
<td>Post-Ruminal</td>
<td>19</td>
<td>27 (0.75)</td>
<td>12 (0.92)</td>
<td>15 (0.94)</td>
</tr>
<tr>
<td>Total Tract</td>
<td>87</td>
<td>91 (70:30)</td>
<td>99 (88:12)</td>
<td>99 (85:15)</td>
</tr>
</tbody>
</table>
**Starch Digestibility of Corn in Lactating Dairy Cows** Owens & Zinn, SWNC, 2005

<table>
<thead>
<tr>
<th></th>
<th>Dry Rolled</th>
<th>High Moisture</th>
<th>Steam Rolled or Flaked</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Diet Observations</td>
<td>14</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>% of Starch Intake</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ruminal</td>
<td>49</td>
<td>76</td>
<td>54</td>
</tr>
<tr>
<td>Post-Ruminal</td>
<td>42 (0.78)</td>
<td>20 (0.83)</td>
<td>40 (0.88)</td>
</tr>
<tr>
<td>Total Tract</td>
<td>91 (54:46)</td>
<td>96 (79:21)</td>
<td>94 (57:43)</td>
</tr>
</tbody>
</table>

**Impact of Flake Density on Total Tract Starch Digestibility** Owens & Zinn, SWNC, 2005

![Graph showing the impact of flake density on total tract starch digestibility.](image)
### Greater Proportion of Starch Digested in the Rumen

**Potential Advantages**
- Energy from VFA
- Microbial Protein
- Greater total tract starch digestion or total energy

**Potential Disadvantages**
- Low Rumen pH Issues
  - Acidosis
  - Intake
  - Liver Abscess
  - Laminitis

### Greater Proportion of Starch Digested in Small Intestine

**Potential Advantages**
- Energetic Efficiency
  - Paradoxical
    - Gain benefits very hard to document
    - Glucose used by gut tissue
    - > visceral fat deposits
  - Less Rumen pH Issues

**Potential Disadvantages**
- May require more costly processing
- < Ruminal MCP output
- More starch passes into hindgut
  - No MCP from digestion
  - HBS
- Reduced total tract starch digestion & total energy
Primary Factors Influencing Starch Digestibility in Corn Grain

- Processing: i.e. Particle size; Steam Treatment
- Harvest/Storage: i.e. Dry vs. HMC, DM of HM/Maturity; Fermentation Time
- Endosperm Type: i.e. Prolamin; Prolamin-starch matrix; Hardness

Adapted from Pat Hoffman, UW Madison Dairy Sci. Dept.

Floary endosperm: Floary starch is more "open" in structure yet opaque in appearance. At full maturity, dent corn contains about equal proportions of hard to floury starch (versus flint genetics with much more vitreous starch).

Vitreous endosperm: Also called homogamous, corneous or hard endosperm, Primary starch in Flint corn. Ranges from 25% to 60% in dent corn (shelled corn in barley, oats, wheat). Most commercial hybrids are 55-65%. Source of grinding grits. Tightly compacted and translucent. Maximum levels achieved at about 70% kernel moisture. Higher levels in mature, high-test weight, high-density kernels. Existing or filling increases availability. Level of vitreousness increases with maturity and nitrogen fertility.

Germ: embryo and amyloplast cells. Most ash, oil and essential amino acids are in the germ. Germ will be larger in HOC at the expense of starch. For each 1% increase in oil, expect a 1.3% decrease in starch. On the side of the kernel facing the tip of ear.

Crown: Hilum or abscission layer. Also called black layer. Caused by collapse and compression of several layers of cells at physiological maturity. Cool weather can cause premature black layer.

The Starch-Protein Matrix

- Prolamin Zein (4 Types) – αβγδ
- Form on the Starch Granule Surface
- Prolamin Proteins Can Cross-link
- Hydrophobic (not soluble in rumen fluid)
- Increases with kernel maturity
- Encapsulate Starch into a Matrix
  - Sorghum = kafrin
  - Corn = zein
  - Wheat = gliadin
  - Oats = avenin
  - Barley = hordein

Copyright: Patrick C. Hoffman, University of Wisconsin-Madison

Scanning electron microscopy of starch granules in corn: A) starch granules heavily imbedded in prolamin-protein matrix, B) starch granules in opaque corn endosperm with less extensive encapsulation by prolamin-proteins (Gibbon et. al., 2003).

Published with permission: Copyright (2003) National Academy of Sciences, U.S.A.
Vitreous Endosperm
Floury Endosperm
Germ
Black (abscission) Layer
Pericarp

Figure 17. Kernels on a light table (left) and modification classes in F2 seed from normal x QPM donors.
Source: Adapted from Krivanek and Vivek (2006).
HMC & Corn Silage StarchD

- Hybrid selection for kernel endosperm properties to improve StarchD very slow to evolve
- Genetic effects on StarchD tempered
  - Harvest should be completed pre- or at blacklayer
  - Kernel processed during or at harvest
  - Prolonged silo storage increases StarchD
- No standardized agreed upon method for assessing differences in StarchD among samples
  - Test Sample/Assay Sample particle size a challenging confounder
  - Ruminal vs. post-ruminal starch digestion
StarchD

- Genetic or transgenic modifications studied
  - Comparisons of Flint, Dent, Reduced-Vitreousness Dent, Floury, Opaque, Waxy Endosperm in Conventional Hybrids (numerous citations but few feeding trials)
  - $\alpha$-Amylase expressed in kernel (Hu et al., 2010, JDS; trials in progress)

HMC Silo Fermentation
Increases Starch Digestibility
Increasing Length of Storage Increases Starch Digestion in HMC

Benton et al., 2004
Univ. of Nebraska

Recommended Moisture Contents

<table>
<thead>
<tr>
<th>Silo</th>
<th>Kernel Moisture %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>27 – 32&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Tower</td>
<td>27 – 32</td>
</tr>
</tbody>
</table>

<sup>a</sup>Earlage/Snaplage target at 35%-45% moisture in product
## Analysis for nutrient composition & fermentation profile on feed-out samples

<table>
<thead>
<tr>
<th></th>
<th>HMSC</th>
<th>Snaplage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch, % of DM</td>
<td>71.2% ± 1.2</td>
<td>61.0% ± 0.8</td>
</tr>
<tr>
<td>CP, % of DM</td>
<td>8.2 ± 0.1</td>
<td>7.7 ± 0.2</td>
</tr>
<tr>
<td>pH</td>
<td>4.4 ± &lt;0.1</td>
<td>4.0 ± 0.1</td>
</tr>
<tr>
<td>Ammonia, % of CP</td>
<td>1.9 ± 0.1</td>
<td>5.1 ± 0.7</td>
</tr>
<tr>
<td>Lactic Acid, % of DM</td>
<td>0.6 ± &lt;0.1</td>
<td>1.3 ± 0.1</td>
</tr>
<tr>
<td>Acetic Acid, % of DM</td>
<td>0.2 ± &lt;0.1</td>
<td>0.5 ± 0.1</td>
</tr>
</tbody>
</table>
Feeding trial conducted during months 8 - 10 in storage

### Snaplage

- Ammonia = 6.0% of CP
- Kernel MPS = 1456 μ

### HMC

- Ammonia = 1.8% of CP
- MPS = 1335 μ

Kd, RSD & TTSD estimated from Ammonia & MPS with FeedGrainv2.0 - Hoffman et al. 2012
Corn Silage Fermentation Increases Starch Digestibility!

Results from Mini-Silo Trial

Ferraretto et al., 2014, ADSA abstracts
Whole-Plant Corn Silage

Grain ~40-45% of WPDM
- Avg. 32% starch in WPDM
- Variable grain:stover

Stover ~55-60% of WPDM
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80 to 98% StarchD
- Processing, particle size
- Fermentation
- Maturity
- Endosperm properties
- Additives (exp.)

40 to 70% IVNDFD
- Lignin/NDF
  - Hybrid Type
  - Environment: G x E
  - Maturity
  - Cutting height
  - Additives (exp.)

Variable peNDF as per chop length

Adapted from Joe Lauer, UW Madison Agronomy Dept.

Corn Silage Quality Indicators for High-Producing Dairy Herds

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Indicates Better Quality</th>
<th>n</th>
<th>Average ± 1 STDEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDF (% DM)</td>
<td>↓</td>
<td>384,715</td>
<td>41 - 36</td>
</tr>
<tr>
<td>Lignin (% DM)</td>
<td>↓</td>
<td>344,134</td>
<td>3.3 - 2.6</td>
</tr>
<tr>
<td>uNDF_{240} (%) NDF</td>
<td>↓</td>
<td>81,418</td>
<td>27 - 24</td>
</tr>
<tr>
<td>NDFD_{30} (%) NDF</td>
<td>↑</td>
<td>170,634</td>
<td>54 - 60</td>
</tr>
<tr>
<td>TTNDFD (%) NDF</td>
<td>↑</td>
<td>27,954</td>
<td>41 - 46</td>
</tr>
<tr>
<td>Starch (% DM)</td>
<td>↑</td>
<td>347,759</td>
<td>32 - 39</td>
</tr>
<tr>
<td>Milk per ton</td>
<td>↑</td>
<td>136,056</td>
<td>3320 - 3683</td>
</tr>
</tbody>
</table>

Summary of combined multi-year, multi-lab (CVAS, DairyOne, RRL, DLL) data, except TTNDFD only from RRL.
Simulations of R.D. Shaver

Whole-Plant NDF & Starch Contents

Proportion of Grain to Stover

Height of Cutting
# High vs. Normal Cut Corn Silage

11 trial average summarized by Wu & Roth; DAS 03-72

<table>
<thead>
<tr>
<th>Item</th>
<th>15 cm Ht.</th>
<th>45 cm Ht.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM, %</td>
<td>38</td>
<td>40</td>
</tr>
<tr>
<td>NDF, %</td>
<td>42</td>
<td>39</td>
</tr>
<tr>
<td>IVNDFD, % of NDF</td>
<td>51</td>
<td>54</td>
</tr>
<tr>
<td>Starch, %</td>
<td>31</td>
<td>32</td>
</tr>
<tr>
<td>Tons DM per acre</td>
<td>8.1</td>
<td>7.5</td>
</tr>
</tbody>
</table>

# Kernel Processing Score

Mertens, USDFRC

- **Ro-Tap Shaker**
  - 9 sieves (0.6 thru 19 mm) and pan
  - Analyze for starch on 4.75 mm & > sieves

<table>
<thead>
<tr>
<th>% of starch passing 4.75 mm sieve</th>
<th>KPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;70%</td>
<td>Excellent</td>
</tr>
<tr>
<td>70% to 50%</td>
<td>Adequate</td>
</tr>
<tr>
<td>&lt; 50%</td>
<td>Poor</td>
</tr>
</tbody>
</table>
Making Sure Your Kernel Processor Is Doing Its Job

by Kevin J. Shinners and Brian J. Holmes

www.uwex.edu/ces/crops/uwforage/KernelProcessing-FOF.pdf

Figure 1: Chopped whole-plant corn placed into water.

Figure 2: Gently agitating material to help the kernels sink to the bottom of the container.

Figure 3: Skimming and removing the floating stover.

Figure 4: Carefully draining the water so only the kernels remain in the container.
Figure 6. Separated kernels showing three levels of kernel processing. Only the material on the right could be considered adequately processed.

Ruminant Starch Digestion

Rumen

Microbial Fermentation
- VFA
- Propionate
- Glucose via liver
- Microbial Protein

Small Intestine

Digestion (Enzymatic)
- Glucose

Hind Gut

Microbial Fermentation
- VFA
Data from literature review of published research trials with steers and lactating dairy cows.

Questions?