Starch Digestibility in Corn Grain and Silage

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Starch in NOT a required nutrient

- Starch is not required in ruminant rations for either the animal or rumen microbes.
- What rumen microbes need is a supply of rumen fermentable carbohydrates as an energy source for growth and microbial protein synthesis
  - This can be supplied by a number of feed components including:
    - Starch,
    - Sugar
    - Pectin
    - Digestible fiber

What cows need is glucose

- Cows derive glucose from either:
  - propionic acid absorbed from the rumen => liver
  - rumen by-pass starch digested in the small intestines
    - Actually more energetically efficient (don’t have methane losses etc)
    - But doesn’t drive microbial yields when digested in the intestines

Kernel Physiology

- The corn kernel evolved to protect the seed until conditions are suitable for germination.
- Fibrous pericarp protecting both embryo and its developmental energy source, the starch-rich endosperm.
- Starch granules are surrounded by hydrophobic proteins that repel water to prevent premature starch hydration that could interfere with germination.
- Seeds were designed to facilitate seed distribution in the feces of plant consuming animals; corn kernels were never designed to facilitate digestion.
Typical Grain Measurements
(primarily driven by food grade requirements)

Test Weight
- Part of the GIPSA Official United States Standards for grain grading criteria.
- Used as a gauge of endosperm hardness by dry millers and alkali cookers (corn chips, corn tortillas).
- Higher TW grain tends to maintain better grain quality in storage, shipping, and handling (e.g., less fines, molding).
- TW is not indicative of either low or high yield, but rather if it is a volume measurement.
- TW and true density are somewhat correlated with more floury genetics typically having lower TW and density.
- However, only about 40% of the variation in grain density can be attributed to variation in TW due to influence of kernel size, shape, maturity, germ content, and pericarp slickness on TW measurements.
- High TW corn will take less storage space than corn with a lower TW test.
- TW increases with kernel dry-down (moisture loss) because dry matter is concentrated in the kernel.
- The official test involves filling a test cup of known volume through a funnel held at a specific height above the test cup to a point where grain begins to pour out of the sides of the test cup. A strike-off stick is used to level the grain in the test cup, and the grain remaining in the cup is weighed.
- Grain weight in the cup is then converted to weight per Winchester bushel and reported as lb/bu.
- Due to TW increasing with grain dry-down, the moisture content of the sample is also reported.
- It is recommended that the sample be between 12 and 16% moisture for analysis.
- Most food grade corn users desire TW higher than 60 lb/bu with some requesting a minimum of 62 lb/bu.
- Typical values are 64-66 lb/bu with a typical range of 60-67 lb/bu.
- 96 lb/bu is required for No. 2 Grade corn.
- Grain with <54 lb/bu are usually charged a dockage on delivery.

Sources:
- http://www.ilcrop.com/ipglab/corntest/corndesc.htm#TestWeight

True Kernel Density
- Measure of weight per unit volume.
- Calculated by dividing the weight of a sample of 100 externally sound kernels by the volume of the same 100 kernels.
- TW is obtained using an analytical balance with a minimum of four decimal places.
- Volume is determined using a helium pycnometer.
- Two-100 kernel replicates are averaged.
- Due to true density (like test weight) increasing with kernel dry-down, moisture content is also reported.
- It is recommended that the sample be between 12 and 16% moisture for analysis.
- Reported as density (in grams per cubic centimeter), 100 kernel weight (in grams), and average kernel volume (in cubic centimeters).
- TW does not indicate either low or high yield, but rather if it is a volume measurement.

Sources:
- http://maize.agron.iastate.edu/corngrows.html
- http://www.ilcrop.com/ipglab/corntest/corndesc.htm#food
Test Weight and Kernel Moistures

First and foremost, growers should understand that test weight and grain moisture are intrinsically related. The higher the grain moisture, the lower the test weight. As grain dries in the field or in the dryer, test weight rapidly increases as long as kernel density remains constant. Test weight removes as grain dries partly because kernel volume tends to shrink with drying and so individual kernels pack into a volume bushel and partly because older grains is drier which tends to encourage kernels to pack more tightly in a volume bushel.


Other Reasons for Low Test Weight

Soybeans, bony, and shriveling; drought damage; improper drying; poor drying; and fungal infestations can cause a significant reduction in test weight and grain density. Reducing test weight can also result in significant depression in yields, particularly when moisture content is above 16%. The difference in test weight is due to the success or failure of the grain filling period in some fields, resulting in less than optimum starch degradation in the kernels. FIBs, also known as foam interferences, occur in corn storage, milling, and in whole plant death that effectively made it not to the grain filling process with the standard production extremes except.

Floury vs. Vitreous Endosperm

Common Terminology

dent vs. flint grain
floury vs. vitreous starch
soft, porous vs. hard, dense
light vs. heavy test weight
floury vs. horny endosperm
opaque vs. translucent

What about Floury vs. Vitreous Endosperm

Extent of vitreousness best determined by:

- Physical dissection
- Measuring absolute density (not test weight)
- Stenvert mill grinding method

Floury

Vitreous

Be Cautious of “high-level” Summaries

Starch in manure can’t make milk

Floury versus Vitreous grain

Research Trial Considerations

- Care is needed to assure that sample handling and vitreous ranges being tested in research studies are realistic.

- Extrapolating results from studies (Correa et al., 2002; Ngonyamo-Majee et al., 2008) on kernels assayed as unfermented grain to the feeding of fermented high-moisture corn or corn silage is suspect to interpretation

- Other studies have investigated starch digestibility using extremes in vitreousness ranging from 3% to 66% (Taylor and Allen, 2005a,b,c) or from 25 to 66% (Allen et al., 2008) of the starch being vitreous.

- Although such wide extremes in vitreousness (and presumably prolamin content) may aid in the understanding of how one specific mechanism can limit starch digestion, caution should be exercised when applying these findings (or production expectations) to field situations where rations are built around commercial hybrids with a much narrower range in vitreousness (typically 55-65%).


When Interpreting Research Results on Floury versus Vitreous Hybrids Give Consideration to the Level of Vitreousness and Maturity of the Grain

You have to be a critical thinker in this business.
When Interpreting Research Results on Floury versus Vitreous Hybrids Give Consideration to the Level of Vitreousness and Maturity of the Grain

<table>
<thead>
<tr>
<th></th>
<th>Floury</th>
<th>Vitreous</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMI, lb/MI</td>
<td>51.9</td>
<td>56.1</td>
</tr>
<tr>
<td>Meal size, lb</td>
<td>4.8</td>
<td>5.4</td>
</tr>
<tr>
<td># Meals/day</td>
<td>10.8</td>
<td>10.4</td>
</tr>
<tr>
<td>Meal Length, min</td>
<td>28.0</td>
<td>28.4</td>
</tr>
<tr>
<td>3.5% FCM, lb</td>
<td>87.3</td>
<td>89.9</td>
</tr>
<tr>
<td>FCM/DMI</td>
<td>1.68</td>
<td>1.60</td>
</tr>
</tbody>
</table>

**TRIAL FINDINGS**

- If feeding normal corn silage:
  - Data suggests using vitreous grain because of increased DM intake and milk yield when fed with control silage
  - **Vitreous increased meal size**
    - Yet, milk efficiency worse with vitreous grain supplementation

**Research Trial Considerations**

- An *in vivo* study by Corona et al. (2006) used **four hybrids within the more typical range in vitreousness (55, 61, 63, and 65%)**
  - Increasing vitreousness of dry rolled corn failed to significantly impact ruminal disappearance of starch but surprisingly, tended to reduce post-ruminal digestion.
  - As noted from other studies, differences in starch digestion due to vitreousness were obliterated when hybrids were steam flaked.

**The impact of vitreous starch must be discussed within the specific method/maturity of corn harvest...**

- **Corn Silage**
  - Vs.
  - **HMC**
  - Vs.
  - **Dry Corn**

**Silage growers and nutritionists should be aware...**

...that when a seed company talks about “soft-texture” they are referring to the kernels evaluated at **dry-grain** maturity, *not* at HMC or corn silage maturities

**...and that no seed company can give you test weight, density or vitreousness data at CS or HMC maturities**
2005 Minnesota field trial assessing the level of vitreousness in hybrids at silage harvest maturities

- Protocol:
  - Just prior to silage harvest, ears from a minimum of 5 representative plants of selected hybrids grown around Rushford, MN (SE MN)
  - Select hybrids that are of similar maturity ratings
  - Harvest ears at silage maturities and snap the ears in half.
  - Pick off enough kernels from the center part several of the ear to fill a pint size milk carton.

In this 2005 Minnesota field study, Pioneer hybrids were lower in vitreousness at silage maturity than the supposedly “soft-texture” hybrid.

- Just because a hybrid is listed as soft-texture (low test weight) in the grain catalog, it does not necessarily equate to softer texture or lower in vitreousness at silage or HMC maturities.

Kernel pycnometer measurements allow for measurement of kernel vitreousness

- Picture from Pioneer Analytical Lab (Urbandale, Iowa) showing a nitrogen gas displacement pycnometer used to measure density of irregular shaped objects (e.g. corn kernels)
  - density reported as grams/cc
- Equations exist to relate density to % kernel vitreousness

Published references that indicates vitreousness not a factor when corn is fed as silage

- 2002 work on vitreousness, per se, out of Randy Shaver’s lab in Wisconsin reported that.... Ruminal starch availability showed a decline after the BL (blacklayer) stage of maturity....


No drastic changes in vitreousness from half milk line to fully mature (and this trial did not include post-animal effect on STRC)

If you have not harvested your corn silage by black layer, you have missed the harvest window!


<table>
<thead>
<tr>
<th>Stage of Maturity</th>
<th>DM %</th>
<th>Vitreousness</th>
<th>Density, g/cm³</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>HM</td>
<td>62.0</td>
<td>42.8</td>
<td>45.2</td>
<td>Correa</td>
</tr>
<tr>
<td>BL</td>
<td>64.1</td>
<td>46.2</td>
<td>48.9</td>
<td>Correa</td>
</tr>
<tr>
<td>MT</td>
<td>64.7</td>
<td>46.1</td>
<td>49.2</td>
<td>Correa</td>
</tr>
<tr>
<td>SEM</td>
<td></td>
<td>1.9</td>
<td>0.83</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Published references that indicates vitreousness not a factor when corn is fed as silage

• 2002 work on vitreousness, per se, out of Randy Shaver’s lab in Wisconsin reported that....Ruminal starch availability showed a decline after the BL (blacklayer) stage of maturity....

Note: This study was conducted with fresh kernels that had not undergone any of the effects of fermentation

Starting at the early-dent stage of maturity, the middle portion of nine ears of the U.S. hybrids was evaluated twice a week and harvested at three maturity stages: one-half milk line (HML), black layer (BL), and 21 d after BL maturity. Maturity was defined by the number of days in the interval between the planting date and harvest date. Kernels were frozen, shelled while frozen, and dried at 60°C for 48 hours.


2005 paper out of Denmark looking at starch digestibility of a very flinty French hybrid harvested (and processed) as corn silage at 25, 35 and 40% DM....

– the ruminal starch digestion did decrease from 93 to 91%....when the fresh crop was analyzed.
– After the crop was fermented, no difference in ruminal starch digestion was detected due to maturity even in this flinty germplasm harvested as mature as 40%DM!

Source: Jensen et al. Animal Feed Science and Technology. 118:3-4, 279-294

Pioneer Research addressing the “Hard Starch” Question

2005 Corn Silage Digestion-Site Study
Dr. Fred Owens
Pioneer Research Scientist

In conjunction with Dr. Richard Zinn Desert Research & Extension Center University of California

Packed in plastic bags inside 55 gallon drums
Drums placed on pallets
Transported

Ensiled for 3 months and shipped to California
The reason UC-Desert Research Center was chosen was to gain access to multiple cannulated cattle to separate starch digested in the rumen vs. SI vs. LI. Each silage was fed (2.2% BW/day) to 10 heifers (310 kg) equipped with duodenal and ileal cannulas in 5 periods. Intakes were low compared to lactating dairy cows. They likely produced less saliva, but also chewed the forage to a greater extent.

Measurements: Undigested Marker (Cr), DM, Ash, Starch, NDF at each site. Calculate disappearance in each segment and in the total digestive tract.

Now taking this same hypothetical hybrid, but harvesting it at HMC maturities
- Corn Silage
- HMC
- Dry Corn

The same hybrid harvested at these different maturities will have completely different STRD....

Is starch from higher vitreous HMC hybrids less digestible?

University of Idaho (under Dr. Carl Hunt)
2004 Ph.D. thesis by Josh Szasz
Sponsored by Pioneer with technical assistance from Dr. Fred Owens

<table>
<thead>
<tr>
<th>Hybrid</th>
<th>Type</th>
<th>Test Wt</th>
<th>Score</th>
<th>Low</th>
<th>Med</th>
<th>Wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>35Y54</td>
<td>Floury</td>
<td>4</td>
<td>27.7</td>
<td>32.6</td>
<td>36.0</td>
<td></td>
</tr>
<tr>
<td>36B08</td>
<td>Flinty</td>
<td>7</td>
<td>28.5</td>
<td>30.0</td>
<td>35.4</td>
<td></td>
</tr>
</tbody>
</table>

Ensilaged at 3 different moistures and stored for >60 days

Source: F.N. Owens, Pioneer Research

Site of Starch Digestion

Not much difference in rumen digestion (green) and when it was lower, it was made up for by increased digestion in the small intestines (dark yellow).

Though starch digestion differed among these samples, the range in total tract digestibility was quite small (1.7%). All samples had total tract starch digestibility greater than 96%.

Source: Dr. Fred Owens, Pioneer Senior Research Scientist

How digestive is starch from HM corn grain?

Review of literature 1990-2005 (45 trials)

High moisture corn has much greater starch digestion than rolled corn. Whole corn had very low starch digestibility.

- With high moisture corn, fermentation increases starch digestion
- HMC has grain at a moisture levels “similar” to corn silage so by inference, starch digestibility should also be high for corn silage

Source: Dr. Fred Owens, Pioneer Senior Research Scientist

Impact of corn type on total tract starch digestion

Vitreous hybrid was slightly less digested in the rumen, but overall by intestinal enzymes.

Source: F.N. Owens, Pioneer Research
A “Non-Issue” in Silage or HMC
Starch Digestibility of Corn - Silage and Grain

Jeffrey L. Taylor
Department of Animal Sciences
The Ohio State University

Presented at the Tri-State Nutrition Conference
April 25-25, 2006

And finally, taking this same hypothetical hybrid, but harvesting it as dry corn grain

• Corn Silage
• HMC
• Dry Corn

U of NE research reinforces that vitreousness does make a difference when the corn is fed as dry rolled corn grain

- This data agrees with Pioneer research that hybrids with softer texture and larger seed size may have superior feeding value when fed as dry rolled grain in finishing beef cattle diets.
- However, these findings should not be extrapolated to hybrids fed as steam flaked, high moisture grain, corn silage OR DRY GROUND (<1000u)

Why Use Isolation Plot Samples? Pollen influences kernel characteristics of all 12 sets of genes that control endosperm characteristics: Sugary, Waxy, Brittle, Soft starch. When cross-pollinated, these factors are NOT characteristic of the hybrid (two gene sets from female; 1 from male-pollen).
The biggest impact on ruminal starch digestion is the form in which it is being fed (e.g., dry rolled vs. high moisture), not hybrid genetics.

![Steam Flaking Corn](image)

When fed as high moisture corn or steam flaked, the ruminal starch digestibility differences are extremely small (1-2%).

When fed as dry rolled grain, ruminal starch digestibility between hybrids did differ by 10%.

Bottom line - moving from HMC to dry rolled corn will alter the amount of ruminal starch availability much more than the relatively small differences between hybrid genetics for ruminal starch digestibility when fed as dry rolled corn.

The drawback of feeding dry rolled grain (~1200 microns) is the amount that escapes into the feces.

Conclusions about Vitreousness in Corn

- Different hybrid/kernel characteristics are desired for different harvest and processing methods.
  - For corn fed as dry, ground or rolled grain, the starch from very finely processed, more floury endosperm hybrids (with a thin or loose seed coat) will be more extensively degraded in the rumen compared to starch from more vitreous hybrids.
  - this ruminal STRD increase may or may not be of benefit depending upon other ration ingredients, the need for microbial protein production and the possible desire to shift starch digestion to the intestines to reduce the potential for ruminal acidosis.

- For corn fed as corn silage, high-moisture corn or steam flaked, more hermetic hybrids with large kernels (reduced pericarp:endosperm ratio) appear preferable.
  - the processes of ensiling (protein matrix solubilization and acid hydrolysis) or flaking (physical gelatinization) will minimize most adverse effects of vitreousness
  - total tract starch digestion in these feeds, if processed correctly, typically exceeds 97%

When is floury starch more digestible than vitreous starch?

- Only when the grain is fed as in the form of dry, rolled corn (likely no advantage if finely ground…e.g. 800-1000 microns).
- No benefits in cattle performance have been detected from feeding floury hybrids either as high-moisture corn or corn silage.

- Limitations of floury grain:
  - More fine particles (rapid burst of fermentation after a meal) contributing to acidosis and depressed performance.
  - Less ruminal starch escape (lower energetic efficiency?)
  - More fragile kernels (more #2 and #3 USDA grades with grain handling)
  - More flake fines; fragile flakes (wet roughage or byproducts help avoid diet and bunk separation of fines).
Hybrid Selection Implications

- Both agronomic and nutritional factors must be considered when selecting grain or silage hybrids.
  - Nutritionists often are unaware or unfamiliar with agronomic considerations involved with grain or silage production because their responsibility is to optimize performance and profitability of animals fed harvested crops.
  - Conversely, some seed companies and their sales force do not fully recognize or appreciate the importance of nutritional factors because they will be judged based on plant standability, disease/pest resistance and yield.
- Solely focusing on either quality or quantity traits fail to recognize the complex interactions among hybrid genetics, harvest maturity, feed type (dry vs. fermented), processing method, particle size and potential associative effects with other ration ingredients.


Sieveing Corn Grain and HMC

<table>
<thead>
<tr>
<th>Mean particle size of corn grain</th>
<th>Effective Rumen Digestibility</th>
<th>Rumen Degradable Starch, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracked</td>
<td>4368</td>
<td>76.4</td>
</tr>
<tr>
<td>Cracked curved</td>
<td>2977</td>
<td>85.4</td>
</tr>
<tr>
<td>Fine ground</td>
<td>868</td>
<td>94.7</td>
</tr>
<tr>
<td>Starchified</td>
<td>2596</td>
<td>99.9</td>
</tr>
</tbody>
</table>

Source: www.seedburo.com/online_catalog/categ08/us_sieve.asp

We know grain particle size exerts a tremendous influence

Table 2. Corn grain particle size and ruminal starch degradability

Particle Size Averages (microns)

<table>
<thead>
<tr>
<th></th>
<th>Corn Grain</th>
<th>HM Corn</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>638</td>
<td>325</td>
</tr>
<tr>
<td>Average</td>
<td>846</td>
<td>1506</td>
</tr>
<tr>
<td>Minimum</td>
<td>339</td>
<td>526</td>
</tr>
<tr>
<td>Maximum</td>
<td>2931</td>
<td>3259</td>
</tr>
</tbody>
</table>

Source: www.seedburo.com/online_catalog/categ08/us_sieve.asp

The Bottom Line

- The economic and ruminal health implications of starch digestibility are immense.
- Digestion of corn grain by dairy cattle appears to be impaired primarily by large particle size and pericarp shielding the endosperm.
  - To a lesser extent, starch fermentation rate can be reduced in mature, dry corn depending on the level of protein-shielding (presence of prolamin proteins, commonly called zeins), that surround and link the starch granules in the portion of the endosperm containing more dense, vitreous starch.
- Fine grinding will increase starch digestion by cattle but more extensive processing methods such as ensiling or flaking greatly minimize or obliterate the effect of vitreousness on starch digestion.
  - In addition to increasing total tract digestion, extensive processing also can shift site of starch digestion.
- Studies investigating the extremes in vitreousness (and presumably in prolamin content) have provided valuable insight into the biochemical and physical mechanisms that limit the rate of starch digestion.
  - Caution should be exercised when attempting to apply these observations to field situations that use rations containing productive, commercial hybrids with a more intermediate level of density.
- Furthermore, research results based on studies with dry, unfermented kernels typically do not apply when grain processed (fermented as high-moisture corn and corn silage or shredded) prior to feeding.

Source: Dave Taysom, Dairyland Labs

The Bottom Line

- Until there is a better understanding of the variability and magnitude of cereal characteristics needed to influence animal performance, there appears room, on most dairies, for near-term focus on quantifying and managing the variability routinely experienced in corn grain and corn silage related to:
  - kernel moisture/maturity,
  - starch content,
  - particle size/distribution and
  - the increase in starch digestibility associated with time in fermented storage.