FIBER DIGESTIBILITY AND STARCH CONTENT OF CORN SILAGE

Neal P. Martin, David R. Mertens, Mary Beth Hall, and Joe G. Lauer

ABSTRACT

Corn silage is a major forage crop in Idaho, supporting its dairy industry. Corn silage produces more digestible energy per acre than other forages. Nutritionally, corn silage is palatable when ensiled properly, and high in energy because it typically contains 50% corn grain. Digestibility of starch declines as the kernel matures. Effective roller processing of corn silage ensures that most of the energy in corn kernels is readily digested by dairy cows. Fiber digestibility can be measured as in vitro Neutral Detergent Fiber digestibility (NDFD) using different fermentation times (24, 30 or 48-hour). The bna3 gene in corn plants reduces lignin content, increases NDFD in vitro, but may not increase NDFD in vivo. Brown midrib corn silage resulted in additional milk per cow per day from increased dry matter intake, but not improved digestibility. Corn silage production is most profitable when yield and dry matter digestibility are highest. High yield with low fiber digestibility, low starch availability, or ineffective fiber can result in nutritional problems for high producing dairy cattle.

Keywords: Corn silage, neutral detergent fiber digestion, starch content, and digestion.

ACREAGE AND PRODUCTION

In 2007, Idaho ranked 7th in corn silage production (5,400,000 tons) and 9th in harvested acreage (200,000 acres). Corn silage is a major forage source for Idaho’s dairy production sector (4th largest state in the U.S.).

Corn silage is relatively easy to produce and manage because it is an annual crop that is harvested only once, compared to perennial forages that have to be managed for survivability and harvested several times annually. It also generates the greatest annual yield of digestible energy per acre of any forage. The advent of roller processing during chopping is ensuring that most of the energy in corn kernels is readily digested by dairy cows. Nutritionally, corn silage is high in energy because it typically contains about 50% corn grain. Nutritionists like corn silage because it adds moisture and consistency to mixed dairy rations. Well-preserved corn silage is palatable and seems to improve the intake of mixed rations.

Although the corn silage in a given silo is relatively consistent, this does not mean that all corn silage is alike. The dairy NRC (NRC, 2001) provides chemical composition data for three qualities of corn silage, but they do not encompass the full range in silage qualities that can occur. Compositions provided in Table 1 were derived from relationships among chemical components in a diverse set of corn silages. Note that corn silage is described in terms of fiber level, which is the inverse of starch concentration. However, starch concentration and grain yield per acre are not as closely related. It is possible to have stunted plants with small ears that result in low grain yields per acre, but the concentration of starch in the silage is equal to that of corn with large plants and large ears that have

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high grain yields. Thus, it is difficult to describe the nutritional quality of drought corn because plant size and ear development can vary independently with weather variation during the crop season.

The relationship between maturity and composition is unique for corn silage among forages because it is a mixture of stover and grain. In general, the proportion of fiber and lignin in plants increases as they mature, and this is true for the stover in corn. The lignin concentration of corn stover increases and its digestibility declines with maturity; however, as the corn plant matures after silking, it generates grain that dilutes the concentration and nutritional impact of the relatively mature stover, often resulting in whole plant digestibility that varies little with maturity. Typically, the dry matter digestibility (DMD) of corn silage increases with maturity as grain increases, and the ratio of amylase-treated neutral detergent fiber (aNDF) to neutral detergent solubles (NDS = 100 – aNDF) decreases. Thus, the typical negative relationship between fiber concentration and maturity does not hold for corn silage; and maturity, which is indicated best by dry matter concentration in corn silage, is not highly related to its nutritional quality.

Relative to alfalfa, corn silage is low in protein, ash, and lignin. In addition, the biological value of the protein in corn silage is low because it is low in lysine. Corn silage also is much lower in many trace minerals than alfalfa. Corn silage is similar to alfalfa in aNDF, and higher in non-fiber carbohydrates (NFC) because it is lower in protein and ash. The predominant NFC in corn silage is starch, and corn silage contains very little pectin or neutral detergent soluble fiber (NDSF), as defined by Hall et al. (1997). Starch in corn silage can be readily fermented in the rumen if corn kernels are immature (> 25% moisture) and are adequately processed or chewed. When the starch in corn silage is digested completely, NDS contributes about 2/3 of the total digestibility of corn silage. The aNDF digestibility (NDFD) of corn silage is typically between 50 to 70% at maintenance levels of intake. However, high concentrations of rapidly fermentable starch in some dairy rations may inhibit the digestion of fiber directly or through the lowering of ruminal pH. Although the potential extent of digestion of aNDF in corn silage is higher, its digestion rate is much slower than alfalfa. The combination of starch inhibition and slow rates of fiber digestion may result in less than optimal digestion of fiber in corn silage.

Although corn silage is palatable, it often results in lower intake and production when it is fed as the sole forage in dairy rations, even though these rations appear to be balanced for protein, fiber, and

### Table 1. Typical composition of corn silages varying in fiber content (adapted from Mertens, 2002).

<table>
<thead>
<tr>
<th>Forage description</th>
<th>CP(^a)</th>
<th>EE(^b)</th>
<th>Ash</th>
<th>NFC(^c)</th>
<th>Star(^d)</th>
<th>Pec(^e)</th>
<th>aNDF(^f)</th>
<th>ADF(^g)</th>
<th>ADL(^h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low fiber</td>
<td>8.3</td>
<td>3.2</td>
<td>4.1</td>
<td>48.</td>
<td>31.</td>
<td>1.</td>
<td>36.0</td>
<td>21.</td>
<td>1.57</td>
</tr>
<tr>
<td>Low fiber</td>
<td>8.6</td>
<td>3.1</td>
<td>4.6</td>
<td>43.</td>
<td>27.</td>
<td>1.</td>
<td>40.5</td>
<td>24.</td>
<td>1.91</td>
</tr>
<tr>
<td>Normal fiber</td>
<td>8.8</td>
<td>3.0</td>
<td>5.1</td>
<td>38.</td>
<td>23.</td>
<td>1.</td>
<td>45.0</td>
<td>27.</td>
<td>2.25</td>
</tr>
<tr>
<td>High fiber</td>
<td>9.0</td>
<td>2.8</td>
<td>5.7</td>
<td>33.</td>
<td>19.</td>
<td>1.</td>
<td>49.5</td>
<td>30.</td>
<td>2.59</td>
</tr>
<tr>
<td>Very high fiber</td>
<td>9.3</td>
<td>2.7</td>
<td>6.2</td>
<td>27.</td>
<td>15.</td>
<td>1.</td>
<td>54.0</td>
<td>33.</td>
<td>2.93</td>
</tr>
</tbody>
</table>

\(^a\) Crude protein  
\(^b\) Ether extract or crude fat  
\(^c\) Nonfiber carbohydrates calculated by difference (NFC = 100 – CP – EE – Ash – aNDF)  
\(^d\) Starch  
\(^e\) Pectin, estimated from NFC  
\(^f\) Amylase-treated neutral detergent fiber determined with sodium sulfite and amylase  
\(^g\) Acid detergent fiber  
\(^h\) Acid detergent lignin using 72% sulfuric acid
minerals. It is speculated that rations containing only corn silage as forage may limit intake and production due to excess rapidly fermentable starch, low effective fiber, and/or slow rates of fiber digestion. It is recommended that corn silage comprise between 1/3 and 2/3 of the forage in dairy rations.

NEUTRAL DETERGENT FIBER DIGESTIBILITY (NDFD)

Digestibility of NDF is an important component of forage quality. [Note: digestible NDF (dNDF) has the units % of DM whereas NDF digestibility (NDFD) is the digestion coefficient of NDF and has the units % of NDF.] Increased NDFD may result in reduced physical fill in the rumen over time and allow greater voluntary feed intake (Dado and Allen, 1995), as well as increasing the energy density of diets and microbial N production (Oba and Allen, 2000). Oba and Allen (1999) reported that a one unit increase in forage NDFD in vitro or in situ was associated with a 0.17 kg increase in DMI and a 0.25 kg increase in 4%FCM yield. Increase in fiber digestibility can be accomplished by using brown midrib (bmr) hybrids, selecting highly digestible fiber hybrids such as leafy hybrids, or by raising the cutter head and leaving more of the poorly digested lower stalk in the field. University of Wisconsin corn breeders are developing a highly digestible NDF germplasm that is equivalent in terms of NDFD to bmr, but without the agronomic detriments such as yield reduction and lodging.

Corn silage higher in NDF content and NDFD in vitro compared to corn silage with lower NDF content and NDFD increased DM intake of cows in mid lactation, Table 2. The increase in intake supported more milk production. However, organic matter digestibility in vivo, by the animal was not different.

INTAKE

Changes in the digestibility of fiber can change intake. The in vitro fiber digestibility was greater in bmr corn silage than a conventional hybrid, but in the cow dry matter intake was greater with the bmr, and the total tract digestion of the fiber did not differ between the hybrids. It is postulated that the fiber in the bmr corn silage is digested in such a way that the particles disintegrate more readily, making them pass from the rumen more quickly and leave room for more intake. If intake increases, there is potential for digestibility to decline.

Physically Effective Fiber

It is well know that dairy cows require a minimum amount of fiber that is of adequate particle size to obtain a ruminal environment that minimizes digestive upsets and optimizes fermentative digestion. Both the chemical and physical natures of fiber are important in describing its effectiveness in generating a desirable ruminal environment. Although ruminal pH, volatile fatty acid concentrations, and microbial population characteristics are the best indicators of ruminal health, chewing activity is one of the most readily available indicators of ruminal function, and of fiber

<table>
<thead>
<tr>
<th>Measure</th>
<th>Low Cell Wall</th>
<th>High Cell Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn silage NDF, %</td>
<td>49</td>
<td>53</td>
</tr>
<tr>
<td>Corn silage IVNDFD – 48-Hour, %</td>
<td>58</td>
<td>67</td>
</tr>
<tr>
<td>Diet, % of corn silage</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>% NDF</td>
<td>31</td>
<td>33</td>
</tr>
<tr>
<td>% NDF from corn silage</td>
<td>22</td>
<td>24</td>
</tr>
<tr>
<td>Dry matter intake, kg/day</td>
<td>24.2^b</td>
<td>25.4^a</td>
</tr>
<tr>
<td>Fat corrected milk at 3.5 % fat, kg/day</td>
<td>31.7^b</td>
<td>34.3^a</td>
</tr>
<tr>
<td>Total tract, organic matter digestibility, %</td>
<td>62.1</td>
<td>61.2</td>
</tr>
</tbody>
</table>

1 40 mid lactation cows fed 55 % forage diets
2 Cows with > pre-trial milk yield had > increases (P<0.08)
effectiveness. Both NDF concentration and particle size are related to chewing activity, and the concept of physically effective NDF (peNDF) was proposed to combine these properties in a single measurement. Adequate peNDF in dairy diets is essential for good rumen function that results in proper digestion of the diet and maintenance of animal health and milk fat production. Because corn silage is often chopped finely or processed through rollers, its peNDF is typically 85% of aNDF, but this can vary from 70 to 95%. The recommendation for peNDF in dairy rations is about 21% of dry matter, but this fiber requirement probably increases with increasing NFC in the ration.

**Starch Content**

Starch concentration is a major source of energy in corn silage contributing 50 to 70% of the digestible organic matter. Starch content of corn silage is a function of the proportion of grain in the silage. This can vary with the hybrid and the crop growth environment. Small corn plants with large or multiple ears will have more grain and starch than large plants with small or stunted ears. Starch content of corn silage typically increases with maturity as the grain fills, but its digestibility can decrease as kernels become harder, drier, and more vitreous (Andrae et al., 2001, Figure 1). To capitalize on the increased starch content of more mature corn, the silage must be properly processed to fragment the kernels into fine pieces that permit effective starch digestion. As shown in Figure 1, processing can have greater impact on the starch digestibility of some hybrids than on others because they differ in starch characteristics.

When using laboratory evaluations of fiber or starch digestibility, understand that different methods (fermentation or enzymatic) and lengths of fermentation (usually 24, 30, or 48 hours) will give different values. For NDF, the longer the fermentation, the greater is the digestibility value. For starch, both particle size (Blasel et al., 2006) and the quality of the starch (Hibberd et al., 1982) affect its digestibility. Enzymatic digestibility will be affected by particle size if the analyzed sample is unground (Blasel et al., 2006), but qualities of the starch itself will be evaluated when it is ground. Both particle size and an inherent digestibility of the starch are important.

**EFFICIENCY OF FEED UTILIZATION**

Changes in feed efficiency can change: the amount of nutrients that end up in manure; the cost of supplemental feeds to meet needs that the forages do not; and the amount of forage needed to support the herd. Feed efficiency is calculated as the pounds of milk production (typically, 4% fat-corrected milk) divided by the pounds of dry matter intake. If animals eat more, but give no more milk, feed efficiency decreases. Higher intakes are not necessarily better, unless production also increases.
Both fiber digestibility and starch content and digestibility can affect feed efficiency of corn silage. Starch is more digestible than fiber (if it is processed adequately) and increasing starch content of corn silage will generally increase its available energy density. However, too much starch can be included in dairy rations, especially if peNDF is borderline, which causes ruminal acidosis and depressed ruminal digestion. In this case, cows become sick, resulting in poor digestion and milk production and low feed efficiencies.

Improving the digestibility of fiber and starch will always result in increases in feed efficiency when diets are formulated or “balanced” to take advantage of the improved nutrient utilization. The only negative for improving digestibility occurs if it is linked with a decrease in yield of either fiber or grain.

**UNIVERSITY OF WISCONSIN EVALUATION OF CORN SILAGE**

Yield of corn silage is dependent on genetics, management, and moisture content at harvest. Management factors are plant population, row-spacing, fertilization, planting date, weed control, and pest management. The nutritional value of corn silage depends on the stover and grain ratio, Figure 2. Fiber digestibility and starch content, major factors controlling nutritional value, are influenced by stover and grain composition. The NDF content, NDFD, starch content, and starch digestion are major factors determining nutritional value of corn silage for dairy cattle.

The University of Wisconsin corn silage evaluation program measures yield and forage quality at 18 locations within the state. Unfermented whole corn plant samples are analyzed via Near Infrared Reflectance Spectroscopy (NIRS) for crude protein, starch, and IVNDFD 48-hour. Schwab-Shaver (2003) developed a modification of the summative equations of the Dairy NRC (2001) that includes in vitro fiber digestibility and the digestibility and content of starch in corn silage (TDN1X = DigCP + DigFat + DigStarch + DigNonStarch + DigNDF – 7). Milk per ton of corn silage is predicted from CP, starch and TDN1X and hybrids are evaluated on DM yield, milk per ton, and milk per acre.

Highest performing hybrids in the UW trials have high yield and high forage quality (milk per ton). Milk per acre combines these traits, and hybrids with high milk per acre could be high yielding hybrids with low milk per acre or low forage quality, which may reduce potential for high animal intake or digestibility. Milk per acres is driven more by yield than quality, so hybrids with high DM yield and average or above milk per ton are recommended.
SUMMARY

Corn silage produces more digestible energy per acre than other forages. The fiber digestibility of the stover and digestibility of starch in grain as well as the ratio of stover to grain explain the nutritional value of corn silage. Corn grain that is mature and low in moisture needs processing to make the starch in kernels available for digestion by dairy cattle. Because corn silage has a high grain content, it is important that it also have adequate effective fiber to obtain successful dairy cow utilization of the silage. Corn hybrids provide best forage quality for dairy cows when DM yield and milk per ton are above average across many trials.

Literature Cited


