SILAGES AS STARCH SOURCES FOR COWS

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Introduction

Starch is not a required nutrient for cattle; cows can live healthy and moderately productive lives when fed starch-free diets. Starch, however, is often a very economical source of net energy (a required nutrient) for the cow and fermentable energy for rumen microbes; thereby providing metabolizable protein (a required nutrient) to the cow. Historically, starch provided by corn and other cereal grains has been very cheap in the U.S., but with the burgeoning ethanol industry, demand for corn has increased tremendously resulting in higher prices. The ability of U.S. corn growers to increase supply is uncertain; but at least in the short term, higher corn prices will become the norm. Even at higher prices, starch should be fed to cattle because of its many desirable characteristics. Cereal grains are not the only feedstuffs that contain starch, even though grain processing is often the only consideration given. This paper will discuss how certain silages can contribute starch to the diet.

Starch vs. Fiber

A typical diet fed to lactating cows contains about 70 % carbohydrate (dry matter (**DM**) basis). Of that fraction, approximately 40 to 45 % is neutral detergent fiber **(NDF**), 35 to 40 % is starch and 15 to 20 % is other compounds such as soluble fiber and simple sugars. Over the past several years we have conducted numerous digestion trials with lactating dairy cows fed a variety of diets (Table 1). The primary NDF sources were corn silage and alfalfa silage, but numerous byproducts with high concentrations of NDF were also fed. The primary starch sources were dry ground corn and corn silage. On average, starch was about twice as digestible as NDF. Although diets in our studies contained about 1.2 times more NDF than starch, on average, starch provided about 1.6 times more digestible energy (**DE**) than NDF. The efficient provision of DE is a primary reason starch is such a desirable nutrient. Starch also can be readily fermented in the rumen, providing energy for bacterial protein synthesis. Although source of starch has a substantial effect, generally as starch concentration in the diet increases (up to a point), flow of bacterial protein to the duodenum also increases. Therefore, starch can increase metabolizable protein (**MP)** supply to the cow by stimulating bacterial protein synthesis.

Table 1. Average concentrations and digestibilities of carbohydrates by lactating dairy cows. The means are from a large database (N = 237 observations) we have been compiling over several years and represent a wide range of diets.

	Mean	SD
DM intake, lb/d	45.5	7.8
NDF, % of DM	32.1	5.1
NDF digestibility, %	46.0	10.9
Starch, % of DM	26.3	5.8
Starch digestibility, %	93.0	3.5
Digestible energy from NDF[1], Mcal/d	13.1	5.4
Digestible energy from starch[1], Mcal/d	21.2	5.2

[1]Starch and NDF were assumed to contain 4.2 Mcal gross energy/kg

Sources of Starch

Starch concentrations in cereal grains generally range from about 50 to 70 % of the DM (Table 2). Most byproduct feeds have very low concentrations of starch, but bakery byproducts (highly variable) and wheat midds contain moderate concentrations of starch. Starch is concentrated in the seed of plants; therefore when forages are harvested in the vegetative stage, starch concentrations are low (usually less than about 5 % of the DM). Some forages such as corn, small grains, and sorghum are harvested at various stages of seed development and will contain low to moderate concentrations of starch. Because starch concentration depends on the stage of seed development, starch concentrations within a type of forage can vary widely. The large variation is evident in Table 2 for barley silage. Barley silage has an average starch concentration of 8.9 % and a standard deviation of 8.6 (other small grains silages have similar means and standard deviations). With a normal distribution, approximately 16 % of samples will have less starch than the mean minus one standard deviation (<0.3 % starch in this example). Since starch concentrations cannot be negative, starch

Table 2. Average concentrations of starch in some common feedstuffs (DM basis)[1].

Feed	Starch, %	SD
Corn grain	70.6	5.1
Corn and cob meal	61.4	8.3
Sorghum grain	69.1	15.6
Barley	55.4	7.8
Oats	44.3	9.7
Wheat	62.8	9.1
Hominy	53.7	11.5
Bakery byproduct	44.7	14.8
Wheat midds	25.7	9.2
Corn silage	30.3	7.6
Barley silage	8.9	8.6
Sorghum silage	10.0	9.1

[1]Data Courtesy of Dairy One (Ithaca, NY).

concentrations in this population of barley silage do not follow a normal distribution. In this set of samples, there is likely a population harvested in the vegetative stage (<5 % starch) and a set of samples harvested in the seed stage. In small grain silages, starch concentration increases with advancing development of the seed. Wheat silage harvested at the milk stage, early dough stage, and hard dough stage had about 8, 17, and 22 % starch (Sudekum et al., 1995). At similar stages of maturity, starch concentrations in barley silage are similar to those for wheat silage (Ahvenjarvi et al., 2006), but concentrations in oat silage will be about half the concentration found in wheat and barley silage (Khorasani et al., 1993). Because of the non-normal distribution of starch concentrations for small grain silages, the mean value is not very useful for ration formulation.

On average, corn silage contains about 30 % starch (Table 2). As with small grain silage, starch concentrations in corn silage increase as the seed matures (Figure 1). At the early dent stage, starch concentrations will often be less than 20 % and may exceed 35 % at black-layer. Starch concentrations also vary among hybrids (Bal et al., 2000; Benefield et al., 2006), and stage of maturity likely interacts with hybrid. High chopping corn (leaving more stalk in the field) will also increase starch concentrations by 3 or 4 percentage units (Neylon and Kung, 2003).

Because of tremendous genetic diversity, starch concentrations in sorghum silage are extremely variable. Sorghum is classified as either forage sorghum or grain sorghum, and silages are made from both types. Starch concentrations in forage-type sorghum range from <5 % to about 15 %. Starch concentrations in grain-type sorghum silage range from about 20 to 40 % (Hart, 1990). High chopping of sorghum silage increases starch concentration to a much greater degree than high chopping of corn silage (Hart, 1990). The large standard deviation for starch concentration in sorghum silage (Table 1) likely reflects this bimodal distribution of starch concentrations, which makes the mean value of little use in ration formulation.

Utilization of Starch from Silages

Evaluating the utilization of starch from silages by dairy cows is difficult because typical diets contain starch from at least two sources (the silage and the grain). Assuming corn silage has 30 % starch and the total diet contains 25 to 30 % starch (reasonable range for typical diets), the diet would need to contain 40 to 60 % corn silage (DM basis) for corn silage to provide about half of the dietary starch. Very often differences in utilization of starch from silages are obscured because effects are diluted by the starch provided by the grain, or the two starch sources could counteract opposite extremes in digestibility to normalize actual performance. Because the value of starch depends on its ability to provide fermentable energy to rumen bacteria and net energy to the cow, the digestibility of starch in the rumen and in the total tract are extremely important.

Small Grain Silages

Major factors that could affect digestibility of starch from small grain silage include species (e.g., wheat vs. barley vs oats), maturity (milk stage vs. soft dough vs. hard dough) and mechanical process of the silage during harvest. No differences in total tract starch digestibility (averaged 92 %) were found when lactating cows were fed diets containing barley, oat, or triticale silage (Khorasani et al., 1996). Ruminal starch digestibilities did not differ between silage species and averaged 80 %. In that study, the test forages comprised 50 % of the diet, but they only provided 15 to 25 % of the total starch (the remainder was provided by barley and corn grain). Total tract starch digestibility was not affected (averaged 99 %) as the concentration of barley silage in the diet

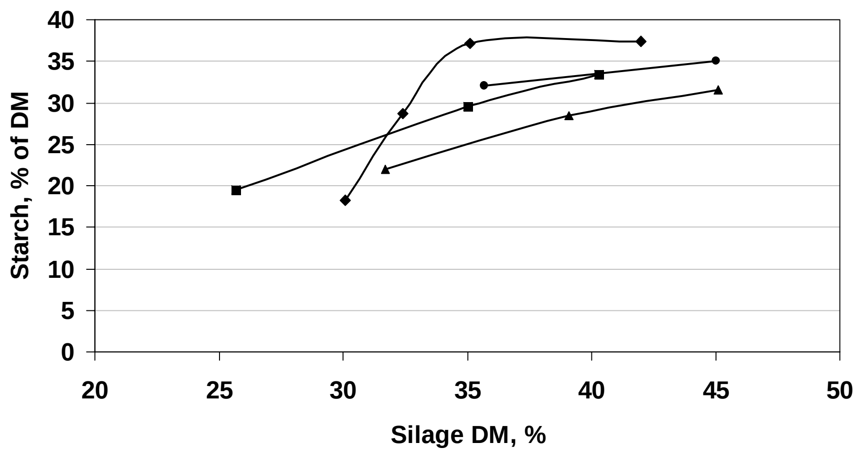

Figure 1. Concentrations of starch in corn silage at various stages of maturity. Each line represents a separate experiment. Hybrid, growing conditions, etc. varies among experiments. Sources of data: Hunt et al., 1989 (triangle); Bal et al., 1997 (diamond); Johnson et al., 1999 (circle); Jensen et al., 2005 (square).

increased from 0 to 60 % (replacing grass silage; Ahvenjarvi et al., 2006). In that study, barley silage provided 0 to 40 % of the total starch in the diet (barley grain and oats provided the rest). In a study with beef steers and wethers in which 90 to 95 % of the starch was provided by wheat silage harvested at late milk stage, early dough stage, and hard dough stage; starch digestibility averaged 99 % and was not affected by stage of maturity, DM intake (maintenance intake vs. 2X maintenance), or animal species (Sudekum et al., 1995). Data on the effect of mechanical processing on digestibility of starch in small grain silage is not available and harvesting methods were not described in the above papers. If *typical* silage harvesting is assumed, additional mechanical processing (e.g., finely chopping the silage) is unlikely to have much effect on starch digestibility simply because starch digestibility is very high. Overall, the starch in small grain silages is highly digestible (slightly higher than average digestibility of starch from dry ground corn grain), and most of the starch is probably digested in the rumen. Although starch from small grain silage is a good source of fermentable energy and digestible energy, its low concentration will limit its overall impact on typical diets fed to lactating dairy cows. Small grain silage could provide a substantial amount of the starch needed by growing heifers and dry cows.

Corn Silage

Site of digestion (ruminal vs. intestinal) and total tract digestibility of starch from corn silage can be affected by hybrid, maturity, and kernel processing as well as by interactions among those three factors.

Corn Silage Hybrid

With the vast number of corn hybrids available some differences in starch digestibility are likely, but based on the available hybrid comparison data differences in total tract starch digestibility by dairy cows have been quite modest. Hybrid differences in starch digestibility could be a result of differences in starch concentration (i.e., the ratio of starch provided by the silage and the grain would differ) or they could result from genetically-caused differences in the structure and chemistry of the kernel. For example, a diet with a higher fiber hybrid had higher total tract starch digestibility compared with a diet based on a conventional hybrid. That difference could have been caused by starch characteristics or it could have been caused by changes in source of starch (silage vs. corn grain; Weiss and Wyatt, 2002).

Vitreousness is a term describing the type of endosperm in the corn kernel. Researchers manually fractionate the components of the starch kernel and measure the proportion of starch in the endosperm that is floury (soft) vs. vitreous (hard). The latter is associated with decreased susceptibility to amylase either originating from microbes or from the animal, in part because of increasing interaction with corn protein. Kernel vitreousness of dry corn grain can affect digestibility of starch (Taylor and Allen, 2005). Some (Bal et al., 2000; Weiss and Wyatt, 2000; Akay and Jackson, 2001), but not all (Nennich et al., 2003) studies suggest that diets with corn silage that have a *softer* kernel have slightly higher starch digestibility (1 to 3 percentage units). Quantitative measures of kernel hardness (e.g., vitreousness) were not done in any of those studies. In one study in which vitreousness of the kernel in corn silage was measured and differed greatly between hybrids (73 vs. 35 %), total tract starch digestibility was only about 1 percentage unit lower for the more vitreous silage (Johnson et al., 2003). The silages in that study only provided about 25 % of total diet starch; therefore, digestibility of starch from the silage might have differed by 4 percentage units. In a data set with different hybrids harvested at different maturities, vitreousness of the kernel post-ensiling was negatively correlated with total tract digestibility (Johnson et al., 2002a). The relationship was different for kernel processed and unprocessed corn silage. For unprocessed corn silage, a 20 unit increase in vitreousness (a large change) would be expected to reduce total tract starch digestibility by just 0.6 percentage units and for processed corn silage a 20 unit increase would be expected to reduce starch digestibility by only 0.2 percentage units. In addition, one must be cautious in using vitreousness rating developed for corn grain or even fresh corn plants because storage as silage can substantially change vitreousness and the change is not consistent among hybrids (Johnson et al., 2002a).

Maturity

As the corn plant matures, the kernel undergoes several changes including reduced moisture concentration, increased vitreousness, and increasing encapsulation of starch granules by a protein matrix. All these are associated with reduced starch digestibility. Depending on the experiment, total tract starch digestibility has decreased from 2 to 10 percentage units as the corn plant matured from about one-quarter milk line to black layer (Bal et al., 1997; Johnson et al., 1999; Johnson et al., 2002b). Likely reasons for that large range include differences in hybrids and in the amount of corn silage in the diet. Kernel processing will also affect how maturity affects starch digestibility.

Kernel Processing of Corn Silage

In the past 10 years, there has been considerable research on kernel processing (**KP**). Building from the foundational work of comparing KP vs unprocessed silages (Johnson et al., 1999), more current research has been documenting interactions in the efficacy of KP among chop length, maturity, and corn cultivars. Weiss and Wyatt (2000) found that KP increased apparent total tract starch digestibility from kernels, while still allowing greater length of chop to increase the effectiveness of the NDF portion. It is very likely that kernel processing will affect starch digestibility differently for different hybrids. In the previous study, the benefit of KP was more pronounced with a conventional hybrid than with a high-oil hybrid, which already maintained higher starch digestibility.

Based on a series of experiments by Wisconsin and Washington State researchers, it is well documented that KP is more beneficial with advancing maturity of the corn. In fact, the DM percentage remains a key diagnostic indicator, even with KP silages (Johnson et al., 2002a). Moreover, increasing DM was highly correlated with vitreousness of the corn kernel in the silage. Further work (Johnson et al., 2003; Ebling and Kung, 2004) demonstrated that total tract starch digestibility was primarily a function of the amount of intact kernels remaining in silage, which obviously depends on whether or not the silage was processed. In immature corn silage, KP will usually have little effect on total tract or ruminal starch digestibility. As the plant matures, KP is more likely to increase both ruminal and total tract starch digestibility. Generally the effect of KP is greater for ruminal starch digestibility (may increase by 5 to 10 percentage units) than for total tract starch digestibility (responses are usually less than 5 percentage units and often only 1 or 2 percentage units; Johnson et al., 2002b). In addition to maturity, variation in responses of starch digestibility to KP can be caused by the way the corn is chopped and processed. Cooke and Bernard (2004) documented reasons for varying particle size (theoretical length of cut, **TLC**) and magnitude of kernel processing (different roller clearance) in the field as farmers try to speed up the time for harvest. Decreasing roller clearance from 8 to 2 mm increased total tract starch digestibility, regardless of TLC. However, the combination of the greater clearance and TLC seemed to negate the benefit on NDF digestibility. These latter values are lower than

Table 3. Total tract digestibility of starch from sorghum silages.

Lactating dairy cows fed different diets with various types of forage sorghum silage (SS) or corn silage (Oliver et al., 2004).

	Conventional SS	BMR-6 SS	BMR-18 SS	Corn Silage
Starch in silage, % DM	10.9	16.8	14.5	19.9
Starch from silage, % of total diet starch[1]	25.0	34.1	30.9	37.9
Starch digestibility, %	85.7[b]	82.3[b]	79.7[b]	91.7[a]

Beef steers fed diets with all starch coming from hetero-yellow grain-type SS harvested at different maturities and different cutting heights (Hart, 1990).

	Soft Dough		80 % Black Layer	
	Low cut	High cut	Low cut	High Cut
Starch in silage, % of DM	25.4	38.1	26.5	38.3
Starch digestibility, %	97.8[a]	96.1[a]	91.3[b]	88.0[b]

[1]Remaining starch in the diet was from ground, dry corn.
[a,b]Within a row, means differ.

expected and might be a result of marker used (indigestible ADF) or from climate (Georgia). However, the interaction of TLC and roller clearance seemed to be largely explained by lower energy-corrected milk and milk efficiency in that last treatment. Clearly, a LC of 1" is too coarse unless the extra power and time are used to fully process the kernels. Moreover, it would be expected that results would be further exaggerated when cows are in free stalls and sorting behavior would be worsened with increased chop length. This trial certainly documents why there could be differences among trials due to actual efficacy of chopping and rolling.

Sorghum Silage

The digestibility of starch (total tract and ruminal) from sorghum grain is usually substantially lower than digestibility of starch from corn grain. With vigorous grain processing (e.g., extensive steam-flaking), differences between the grains become quite small. Few studies are available looking at digestibility of starch from sorghum silage. Because the sorghum grain is less developed when harvested at the silage stage than at the grain stage, differences between starch in sorghum silage and corn silage are likely to be less than when the mature grains are compared. The digestibility of starch from sorghum silage is affected by many of the same factors affecting digestibility of starch in corn silage, specifically maturity and hybrid. Data with silages are not available but based on data with sorghum grain, bird resistant hybrids have substantially lower starch digestibility than hetero-yellow hybrids. Because the forage-type hybrids have low concentrations of starch little information is available. In a study with a conventional forage sorghum and brown-midrib sorghum, total tract digestibility by cows fed sorghum silage (silage provided 25 to 34 % of total diet starch) averaged 83 %, which was significantly lower than starch digestibility of a diet based on corn silage (Oliver et al., 2004; Table 3). If the difference in starch digestibility was caused entirely by type of silage (i.e., no interaction between grain and silage), the starch digestibility of the sorghum silages in this study was about 27 percentage units less digestible than the starch in corn silage (this is extremely low digestibility and suggests some interactions were occurring). In another study, digestibility of starch from sorghum silage was much higher. Steers fed sorghum silage (hetero-yellow grain-type hybrid) as the only source of starch in the diet had total tract starch digestibility of about 96 % when silage was harvested in the soft dough stage and 90 % when harvested at 80 % black layer (Hart, 1990; Table 3). Hart also found in that study that total tract digestibility of starch was higher when all the starch came from silage than when dietary starch came from both sorghum silage and ground sorghum grain (diets were equal in total starch concentrations).

Methods to Estimate or Evaluate Starch Availability

Various methods have been proposed to evaluate starch availability in corn silage including *in vitro, in situ,* and enzymatic incubations and particle size measurements. Data on other starch-containing silages are lacking. Differences among samples (e.g., hybrids, KP, and maturity) can be found with any method, but solid data relating those measures of starch availability to cow responses (e.g., production, ruminal and total tract starch digestibility) are extremely limited. Particle size has a huge effect on starch disappearance when measured using *in vitro,* *in situ*, or enzymatic techniques. If samples are ground before the analysis, important differences may be eliminated. Conversely if no sample processing is done, differences can be exaggerated (relative to what we see *in vivo*) because the particle size reduction that occurs when cows chew and ruminate does not occur. Substantial starch digestion can occur in the intestines; however *in vitro* and *in situ* techniques only include ruminal digestion. Therefore differences observed using *in vitro* and *in situ* techniques will probably overestimate differences that would occur in total tract starch digestibility. An enzymatic-based test called Degree of Starch Access (**DAS**) has been developed at the University of Wisconsin (for details, see http://www.uwex.edu/ces/crops/uwforage/StarchDig-FOF.htm). In this test, samples are not ground prior to analysis but, based on limited data, total tract starch digestibility was correlated with DAS. It was not clear how diets differed in that evaluation and may have included differences in corn grain and differences in corn silage. Ferreira and Mertens (2005) selected 32 samples of widely diverse chemical and physical corn silages being used in the field. The percentage of starch in the particle fraction from a sieve of 4.75-mm (0.187 in) pore size ranged from 8.7 to 100 %. They developed an index based on the starch remaining in this sieve (roughly 1/4 or larger of a kernel) to represent slowly degraded starch, which correlated with *in vitro* disappearance of starch and non-fiber carbohydrate (the by-difference calculation). Although they stated that further *in vivo* testing is needed, this index should be considered for application. Because the Penn State shaker box tends to separate higher (0.31 in for the middle screen) and lower (0.05 in), it is unclear if this index is adaptable to the current Penn State system. In addition, Stone (2004) elaborated on the necessity of calibration of the Penn State shaker box system. To be consistent, calibration probably also would be needed for the 4.75-mm index or any other index as it is adapted from the originating lab to any commercial lab.

Methods currently available should be considered indices rather than methods to estimate *in vivo* starch digestibility. Most of these evaluative methods exaggerate differences relative to what is observed for total tract starch digestibility. *In vivo* differences in ruminal starch digestibility are greater than differences in the total tract and the evaluative methods are better at evaluating differences in ruminal starch digestion. Although not perfect, these methods may help identify possible problems. Silages (or diets) that have extremely high starch availability as measured by these tests may be more likely to cause ruminal acidosis. Results from samples that have low starch availability, as measured by these tests, suggest that rumen fermentation may be lower than desired requiring modification of protein supplementation or total tract digestibility may be lower than expected suggesting changes in energy supplementation.

Conclusions

1. Small grain silages, sorghum silage, and corn silage contain low to moderate concentrations of starch (approximately 10 to 30 % of DM).

2. Digestibility of starch from small grain silages generally is quite high.

3. Digestibility of starch from corn silage is variable (affected by maturity, hybrid and kernel processing). Vitreousness of kernels (after ensiling) is negatively correlated with starch digestibility and kernel processing often increases starch digestibility, but kernel processing probably has a much greater impact than vitreousness. On average digestibility of starch from corn silage is similar to that of corn grain (i.e., changing the ratio of starch from corn silage and corn grain does not greatly affect starch digestibility, on average).

4. Digestibility of starch from sorghum silage ranges from very high (beef steers fed grain-type sorghum silage) to quite low (dairy cows fed forage sorghum). The variation could be caused by type of sorghum (forage vs. grain and bird-resistant vs. hetero-yellow) or by the type of animal fed (perhaps an intake effect).

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