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Maximizing Digestible Intake of Corn Silage-based Diets: Part 2

Mike Allen
Michigan State University
Dept. of Animal Science

Part 2 discusses maximizing energy intake of corn silage-based diets. Part 1 focused on concentration, effectiveness, and digestibility of NDF in corn silage. This article focuses on ruminal starch digestibility and optimizing fermentability of diets.

Starch Digestability
Digestibility of starch in corn silage is highly variable and affected by maturity at harvest, hybrid genetics, and by growing environment. Corn kernels harden as the corn plant matures and becomes drier. As the plant matures, sugar in kernels is converted to starch and moisture concentration decreases allowing the starch granules to become more tightly packed. The moisture concentration of whole plant corn forage must be reduced by drying in the field before ensiling to minimize effluent loss and inhibit growth of undesirable micro-organisms in the silo.

However, in some situations, when corn forage is at the appropriate moisture concentration for harvesting, kernels become too dry and hard and more resistant to digestion. The dry matter (DM) concentration of corn kernels relative to that of the whole plant can vary by as much as 10 percentage units for corn forage harvested at 35% whole plant DM (Allen et al., 2003).

In addition, many corn hybrids have been developed for rapid rate of kernel drying while retaining moisture in the stover. Hybrids with this trait are called “stay-green” because the stalks and leaves stay green (moist) while the kernels dry down. While beneficial for grain hybrids, there is no proven benefit of the “stay-green” trait for silage hybrids and hybrids with a rapid rate of kernel drying likely have reduced starch digestibility.

The endosperm is about 83% of the dry weight of kernels and contains the starch granules (5-30 µm in diameter) embedded in a protein matrix. Kernel texture is affected by type of endosperm: floury or vitreous. Proportions of vitreous and floury endosperm vary among corn hybrids and maturity at harvest. Corn hybrids with kernels containing high proportions of vitreous (or horney) endosperm are glassy in appearance and are called corneous, or flinty and those containing high proportions of floury endosperm are chalky in appearance and are called floury, opaque, or soft (Kotarski et al., 1992).

Degradation of starch from corn by ruminal microbes is related negatively to the vitreous:floury endosperm ratio (Philippeau et al., 1999b; Philippeau et al., 2000) but not related to the amylose:amylopectin ratio of starch (Philippeau et al., 1998). Resistance to degradation by ruminal microbes for starch in vitreous endosperm compared with floury endosperm is primarily because of the distribution of proteins in the endosperm; concentrations of zein proteins increase and glutelin proteins decrease with increasing vitreousness (Philippeau et al., 2000). The insoluble zein proteins limit accessibility to the starch granules by ruminal microbes compared with the soluble glutelin proteins (Philippeau et al., 2000).

Increasing maturity at harvest resulted in increased vitreousness and decreased in situ ruminal starch degradation for both flint and dent hybrids. Also, starch degradability by ruminal microbes was much greater for the dent hybrid compared with the flint hybrid at similar DM concentrations from ~ 30% to ~ 40% whole plant DM (Philippeau and Michalet-Doreau, 1997).

Grain from flint corn decreased ruminal starch digestibility compared with grain from dent corn (34.8% and 60.8%, respectively) when fed to steers in 67% grain diets, but did not affect total tract starch digestibility because of compensatory digestion in the intestines (Philippeau et al., 1999a). In a recent experiment with lactating cows, rate of ruminal starch digestion was faster and rate of ruminal starch passage tended to be slower in diets containing corn grain with floury versus vitreous endosperm, resulting in an average increase for ruminal starch digestibility of 22 percentage units (Taylor and Allen, 2005).

Although compensatory postruminal starch digestion decreased differences among treatments for total tract starch digestibility, starch entering the duodenum was more digestible for grain with floury endosperm compared with vitreous grain, resulting in greater total tract starch digestibility for floury corn grain compared with vitreous corn grain.

Effects of fermentation during ensiling on solubility of endosperm proteins can increase degradation of starch by ruminal microbes. Stock et al. (1991) reported that solubility of endosperm proteins was highly related to moisture level in high moisture corn, and solubility and starch digestibility increased with time of storage.

Philippeau and Michalet-Doreau (1998) reported that ensiling increased in situ ruminal starch degradation for both flint and dent hybrids. Allen et al. (2003) reported that the extent to which in vitro starch digestibility increased with ensiling and time of ensiling was greater as grain moisture content increased.

Ruminal Fermentability of Diets

A primary consideration for formulating diets of lactating cows is the fermentability of the diet; sub-optimal ruminal fermentability will decrease substrate for microbial protein production, decrease DM digestibility and decrease the efficiency of conversion of feed to milk. Excessive ruminal fermentability decreases meal size and feed intake, efficiency of microbial protein production, ruminal pH, and fiber digestibility. Consideration of ruminal fermentability is especially important for corn silage-based diets because of the large variability in fermentability of corn silage.

Ruminal fermentability is often less than optimal when mature corn silage is fed. When corn kernels from silage pass through the cow undigested, DM intake (DMI) often increases as the cow attempts to meet her energy requirements. However, not all cows can increase DMI enough to make up for the lost energy from undigested kernel passage.

Dry matter intake for high producing dairy cows is often limited by the filling effects of the diet. Thus, when these cows consume diets with decreased digestibility, they have little ability to eat more. In contrast, feed intake of lower producing cows is often limited by mechanisms related to absorbed fuels from the diet; as digestibility decreases, intake increases to compensate, at least until gut fill begins to limit intake.

In this case, even though milk production might not be affected, feed costs will increase because more feed is required to produce the same amount of milk. Because the grain in over-mature corn silage is less fermentable, more supplemental grain can be added in the diet in place of forage to increase the energy density.

Alternatively, a more fermentable grain source can be substituted such as rolled barley or high moisture corn for less fermentable starch sources such as dry corn grain.

Processing corn silage by rolling can increase ruminal and whole tract digestibility of kernels but kernels should not be crushed to the extent that they are completely broken into fine pieces: over-processed corn silage (rollers too close) can result in starch that is so rapidly fermented that feed intake, fiber digestibility and milk fat percent are reduced. Additional rumen undegraded protein might be necessary to compensate for lower microbial protein production if ruminal fermentability cannot be adequately adjusted.

Ruminal fermentability is often excessive when corn silage is harvested premature (<30% DM), particularly when supplemented with very high moisture corn (<70% DM). Excessive fermentation acid production can decrease ruminal pH which can reduce fiber digestibility, rumen microbial protein yield and animal health.

In addition, rapid fermentation of ingested feed during a meal produces fatty acid that can cause satiety. Although acetate is the volatile fatty acid (VFA) produced in the greatest quantity in the rumen, propionate has a greater effect on limiting intake (Allen, 2000) and more propionate is produced as fermentability of diets increase.

Feed intake was reduced dramatically by up to 7 lb of dry matter per cow per day when highly fermentable starch sources were substituted in diets for less fermentable sources in several experiments reported in the literature (Allen, 2000). Rapidly fermented starch sources also can decrease efficiency of microbial protein production; rate of starch digestion was related negatively to efficiency of microbial protein production in two recent experiments (Oba and Allen, 2003; Voelker and Allen, 2003).

When large amounts of highly fermentable organic matter (OM) are provided to ruminal microbes quickly, they sometimes uncouple growth from fermentation reducing the microbial protein produced per lb of OM fermented and increasing the production of acids in the rumen that must be neutralized or buffered. Highly fermentable diets are also likely to cause the partition of digestible energy away from milk production towards body condition (Oba and Allen, 2000).

The ruminal fermentability of diets is easily manipulated in diets altering the fermentability of supplemental cereal grains. Ruminal starch fermentation ranges from less than 40% to greater than 90% depending upon sources, variation in particle size, gelatinization of starch, and amount and solubility of endosperm proteins.

Dry rolling and grinding decrease particle size of grains, which increases surface area of the grain available to microbes and therefore, rate of fermentation. Steam rolling or flaking increase surface area and also gelatinizes starch, which increase accessibility by microbes and rate of fermentation. Different grain types such as wheat, barley, corn, and sorghum have major differences in amount and solubility of endosperm proteins that dramatically affect rate of fermentation.

Wheat and barley have low concentrations and greater solubility of endosperm proteins, resulting in greater rates of fermentation than corn or sorghum. Corn grain hybrids have a wide range in amount and solubility of endosperm proteins. High moisture fermentation results in proteolysis and an increase in the solubility of endosperm proteins, increasing rate of starch digestion.

The optimum ruminal fermentability of diets for dairy cows is likely affected by milk production level and management factors such as bunk space per cow and feeding system and is therefore unlikely to be the same across all groups of cows. Furthermore, our current inability to accurately predict ruminal fermentability of OM limits our ability to formulate diets without evaluating cow response. Indicators of expected cow responses to differences in ruminal fermentability of starch and fiber are listed below.

Indicators of poor starch digestibility (often observed with over-mature corn silage or corn silage with vitreous endosperm):
- increased feed intake for cows across production levels;
- consistent feed intake;
- lower milk yield for high-producing cows;
- poor conversion of feed to milk for cows across production levels;
- elevated milk fat concentration;

• positive response to increased diet fermentability; and
• possible response to increased rumen undegraded protein.

Indicators of excessive diet fermentability:
• depressed feed intake particularly for lower-producing cows;
• greater daily variation in feed intake;
• low milk fat particularly for lower-producing cows;
• increased fluidity of manure; and
• positive response to substitution of less fermentable starch source with higher whole tract digestibility (such as dry ground corn).

Indicators of poor forage NDF digestibility:
• depressed feed intake and milk yield for high-producing cows; and
• greater feed intake for lower-producing cows.

Evaluation of cow response to diet changes combined with the knowledge of what factors affect ruminal fermentability and the effects of changes in diet fermentability on animal response are an important part of proper diet formulation for the foreseeable future.

Conclusion

Concentrations and ruminal fermentability of NDF and starch are highly variable across corn silage hybrids and must be considered when formulating diets for lactating cows. While concentration of NDF and starch is easily adjusted for by varying supplemental grain, variation in digestibility of NDF and starch can affect feed intake and milk yield because of our limited ability for diet adjustment. The large variation in ruminal and whole tract digestibility must be considered when formulating diets to maximize milk yield from corn silage-based diets.

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