

Using Starch Digestibility Information in Ration Balancing

Charles J Sniffen¹ & Ralph Ward²

¹Fencrest, LLC, Holderness NH 03245

Email: Fencrest@msn.com

²Cumberland Valley Analytical Services, Maugansville, MD 21767

Email: rward@foragelab.com

■ Take Home Messages

- ▶ We are now close to having a means to formulate rations for ruminal starch degradability.
- ▶ We have a beginning 7 hour *in vitro* starch degradability measurement which we can use in nutrition programs in a static mode or in a dynamic mode by generating rates of digestion. Tentative guidelines are provided that can be used in either a static or a dynamic mode.
- ▶ With increased sophistication of *in vitro* or even possibly enzymatic analyses, it might be possible to formulate for a fast pool of starch and a slow pool of starch.
- ▶ The next challenge is a refinement in our starch digestion models to predict digestion of starch escaping ruminal fermentation in the small and large intestine.

■ Introduction

Starch degradability is a rapidly evolving story. The intense interest in starch degradability grew out of the work done by Allen at Michigan State (Taylor & Allen, 2006) in high producing cows and from the high cost of corn in an economy that has been extremely poor. Additionally, the work at Wisconsin on vitreousness and just lately the Wisconsin work on prolamin proteins in corn have highlighted the differences among corn silage hybrids and different sources of corn grain (Correa et al., 2002). The driving force, however, has been the economy. Milk prices have been low in the USA and corn prices have been high. This has resulted in concern on the digestibility of the starch, especially when we see it in the manure.

■ The Problem

Corn and sorghum grains are known for variability in ruminal starch availability in the kernel. This has led to a whole industry, primarily in the Southwestern USA, dedicated to steam flaking, steam rolling, popping, and roasting to improve the starch digestibility from our starch sources (Huntington, 1996). It has also led to the long-term industry practice of grinding the grains to a fine particle size to improve starch availability.

The basic problem is that as the kernel matures, there is an increasing % of the starch that is protected by prolamin proteins. These proteins are insoluble in the rumen as well as difficult to digest in the small intestine and are identified as the vitreous endosperm. This can be seen below (Figure 1) with the diagram on the right showing the more floury type hybrid at the top.

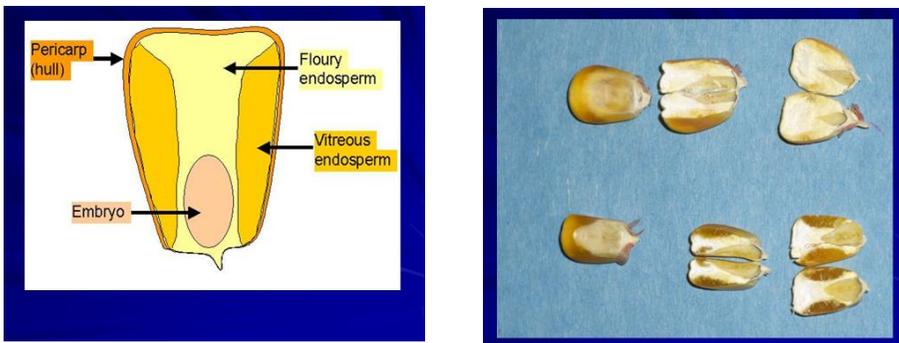


Figure 1. Floury and vitreous corn types (Lutz, 2007)

The hybrids developed in the USA have primarily been for grain production, resulting in hybrids with high grain content that can stand up to a lot of handling without breaking down. These hybrids, generally speaking, tend to be highly vitreous. They also have a higher bushel weight. Unfortunately, the ruminal starch availability from these grain sources is lower, mostly in the rumen but also in the whole tract. Here, we are talking about dry grain. The way to increase the starch availability is to steam flake the corn which results in the partial breakdown of the prolamin proteins. Finely grinding corn can also fracture these proteins, increasing the surface area, resulting in better utilization.

Prolamin proteins are a large family of plant proteins and contain among them poor quality proteins that are soluble in ethanol/water (Larson & Hoffman, 2008). The main protein in corn is zein proteins, which are poor quality with low levels of lysine and tryptophan. These are storage proteins. Because of their insolubility in rumen fluid, they are poorly digested in the rumen. They are also poorly digested in the small intestine. The starch granules are

heavily imbedded in these zein matrices. Either we need to grow hybrids that are low in these proteins or we need to process the corn in a manner that will disrupt the matrix.

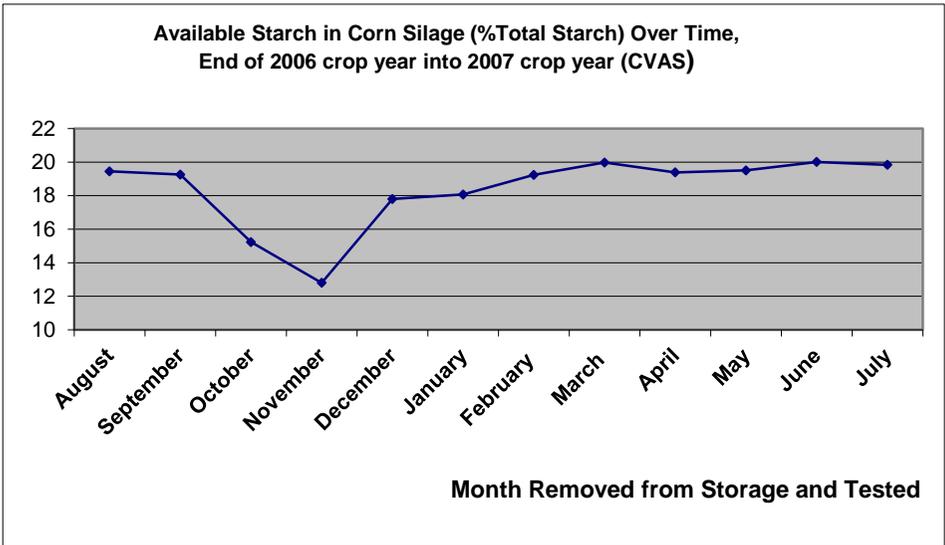


Figure 2. The effect of time of harvest on starch degradability, using a one hour enzymatic assay.

We have been learning a few things of interest about corn silage. Figure 2 represents an enzymatic assay done by Cumberland Valley Analytical Services (CVAS, Maugansville, MD, USA). The data were summarized from the samples that came into the lab. What is interesting is that the samples in October and November which represent the new crop corn silage are lower in starch degradability. The next interesting thing is that it takes until March to get to maximum ruminal degradability.

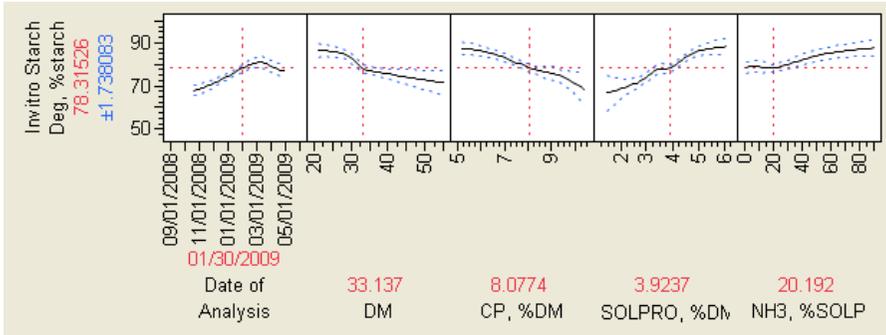


Figure 3. The impact of various factors on *in vitro* 7-hour starch digestibility

In Figure 3 is another dataset from CVAS which in this case is the 7 hour starch degradability measurement. What is of interest first is that this dataset shows that the same phenomenon exists in not achieving maximum degradability until March. Remember the prolamin discussion above. As the corn grain matures, the zein protein develops and results in the starch granules becoming inaccessible by rumen bacteria (Lopes et al., 2009). However, over time, in an acid medium, the zein becomes soluble and the starches will become available. It will be noted that as the dry matter (DM) of the corn silage goes much over 30%, the degradability of the starch decreases. This is because of the increase in the zein content of the kernel. This then fits with the increase in the protein content. The increased soluble protein as a %DM reflects the slow breakdown of the prolamin proteins, mainly zein, with time in the silo. The ammonia levels (NH₃) follow the same trend.

In other work, it has been noted that there are significant differences among hybrids in the amounts of zein proteins in the corn. This means that it is important to ask questions about the hybrids being used in terms of the measurement of the vitreousness or prolamin content.

Table 1 is a guide that Hoffman and Shaver (2009) developed to judge the prolamin content of feeds. Eventually we hope that we will be able to translate this information into nutrition models that are used today.

Table 1. Corn prolamin content classifications.

Prolamin % of Starch	Classification
>10.0	Extremely High
10.0	
9.0	Very High
8.0	
7.0	High
6.0	
5.0	Moderate
4.0	
3.0	Low
2.0	
< 2.0	Very Low

Hoffman & Shaver, 2009

■ Applications

Much corn is fed as high moisture grain. We know from experience that if we store corn at moistures of 26 to 30%, and then roll this corn we optimize the utilization of the starch. If we store the corn at 20 to 24% moisture, experience shows us that we need to grind this corn to a fine state in order to derive the energy from the corn that we desire. We also know that if we store the corn at moistures over 30% we increase the risk of acidosis.

This then brings us to corn silage. For years, we have focused on grain yield per acre as well as total tonnage of silage per acre. We have been able to achieve very high forage and grain yields per acre. But, we have ignored the nutrient characteristics of the corn we are growing. Dr. Mike Allen, Michigan State, many years ago pointed out the importance of considering fiber digestibility. We have finally been accepting the importance of this and have, in recent years, been growing silage only hybrids. However, we have been largely ignoring the availability of the starch in the various hybrids. Part of this is because we really have not had good methods to measure the starch availability. The University of Wisconsin developed a total tract digestibility approach. This could be used to rank the hybrid and possibly to adjust the Processing Adjustment Factor value in the NRC system. Dr. James Ferguson, University of Pennsylvania, suggested that fecal samples could be

taken and using lignin as a marker, estimate the total tract starch digestibility. This helps but what is needed is a measurement of the ruminal starch digestion in a corn silage hybrid or grain source.

Mike Allen developed a 7-hour *in vitro* starch digestibility assay. This approach was developed based on the work that his team had been doing with ruminally and duodenally cannulated cows producing over 45 kg of milk per day. This was the first time that a starch degradability assay had been directly tied to measurements of starch digested in the rumen and whole tract. There have been assays such as 1-hour or 2-hour enzymatic tests which have been available for quite a while at forage testing labs. There has also been available a gas test for several years which has been used to predict rumen availability. The enzymatic tests have been used for many years by the steam flaking industry as a quality control method to adjust the process to the bushel weight they are trying to achieve.

The challenge is to be able to incorporate information about starch degradability into ration formulation programs. In Spartan II, the concept of starch fermentability was introduced many years ago. This has been continued in Spartan 3 with a better definition of the rumen degradability than in the previous platform. I think the numbers in the master dictionary are reasonably close, actually reasonably reflective of the 7-hour starch measurements made by Mike Allen. This is a valid approach but it depends on the book values being correct. The challenge of this approach is the variation as shown above. If, in fact, the starch rumen degradabilities (RD's) in Spartan 3 do reflect the Allen 7-hour values, then it is simply a matter of conducting the *in vitro* starch analysis and putting this number into the program.

For those using the dynamic models in the different platforms life becomes a little more complicated. We need to convert the 7-hour number to a rate of digestion. Basically, the difference between Spartan 3 and CPM/CNCPS 5.0 & 6.1 is that using a rate of digestion (RD) dictates a variable digestion in the rumen, which is dictated by the variable rate of passage. This is assuming that the starch RD's are a surrogate for the 7-hour measurements. The suggested equation to derive the Kd's is:

$$Kd-7, \%h = \left(\frac{\ln(\text{Starch}, \%DM) - \ln\left(\frac{100 - 7H \text{ IV starch Deg, \%starch}}{100} * \text{Starch}, \%DM\right)}{7} \right) * 100$$

This equation assumes no lag. It is possible to put in a lag factor if it is felt necessary. Of interest is that in CNCPS 6.1, there has been a reduction in the Kd's of the starches in corn grain and corn silages. This translates into lower microbial yields, dictating a higher requirement for bypass protein. CNCPS 6.1 also ends up needing about 200 g less protein to balance a

ration, resulting in a lower peptide requirement which combined, dictates a lower CP.

Below (Table 2) is a recent analysis of corn silage. We have been routinely formulating rations for starch for several years, watching our starch sources, knowing that there are differences in degradabilities among the different starch sources. We have been using thumb rules for the concentrations needed in the ration and the consideration of the groups we are feeding and the environment that they reside in.

Table 2. Analysis of corn silage (CVAS, 2009)

CORN SILAGE	As Sampled	Dry Matter	Unit	Range
Moisture	65.3		%	
Dry Matter	34.7		%	31.0 - 36.2
Acid Detergent Fiber	7.8	22.4	% DM	24.8 - 28.6
Neutral Detergent Fiber	13.3	38.2	% DM	44.0 - 49.7
Lignin	1.1	3.1	% DM	3.0 - 3.8
Lignin / NDF Ratio		8.1		
Crude Fat	1.3	3.8	% DM	2.9 - 3.7
Ash	1.1	3.2	% DM	3.6 - 4.6
Starch	11.5	33.2	% DM	24.7 - 31.7
Sugar	0.2	0.6	% DM	
NFC	16.3	47.1	% DM	34.3 - 40.6

Starch analyses have become routine among laboratories. However, it does need to be pointed out that as routine as this assay has become there are still some difficulties, much of the difficulty being among starch sources as well as within starch source. Different laboratories use different analytical procedures.

The silage in Table 2 has a fairly high starch content. You will note the range in starch for corn silages of 25 to 32% starch. In ration formulation, if we can adjust for the total measured starch in the ration, we are a step ahead. We have found that not guessing on the ration starch content has helped us significantly in developing performing rations. However, based on some of the work that has recently been done in Wisconsin and in Michigan, it has become apparent that we needed to move beyond total starch in our formulation. The data above demonstrates the importance of this. The challenge has been to develop an assay that would allow us to estimate degradability in the rumen.

Figure 4 is the starch degradability analysis for the above sample from CVAS. The 7-h degradability is 52.7% of the starch.

A N A L Y S I S R E S U L T S

7 hour invitro starch degradability = 52.7% of starch

Invitro starch degradability is very much dependent on the particle size of the material evaluated. For the 7 hour invitro starch assay, corn grain is ground through a 2 mm cyclone mill and corn silage is ground through a 3 mm Wiley knife mill. These grinding treatments were established to attempt to provide the greatest range in degradability and maintain sample homogeneity.

When possible, requests will be honored to run samples as-recieved or with other processing definitions based on client needs.

Corn grain 7 hour invitro degradability:
 Average: 70.3% of starch
 Std Dev.: 5.6
 Range: 55% to 85%

Corn silage 7 hour invitro degradability:
 Average: 62.0% of starch
 Std Dev.: 9.7
 Range: 40% to 90%

Figure 4. 7-hour *in vitro* starch degradability report. Cumberland Valley

Note the standard deviations and ranges for corn grain and corn silage. Also note in the paragraph above the comments on sample particle size. This is critical in this *in vitro* assay.

Table 3. Rate of digestion analysis calculations for 7-hour *in vitro* starch degradability analysis.

Corn Samples -- CVAS In Situ Analysis				
Example Calculations				
	Starch (%DM)	7 H IV Starch Dig (%Starch)	Lag	Starch Kd (IV)
Coarse Cornmeal (A)	72.6	67.7	0.5	17.39
Steam Flaked Corn (B)	74.7	75.8	0.5	21.83
Steam Rolled Corn -- C	72.2	76.1	0.5	22.02
Corn Silage	33.2	52.7	0.5	11.52

De Ondarza, 2005

Table 3 is a small spreadsheet to convert the ruminal starch digestibility to a rate of digestion based on the equation given earlier. The Kd, %/h of 11.52% is very low compared to the book values that we have been using in CPM Dairy and CNCPS 5.0. This has an impact mostly on microbial yield

predictions. The hybrids on this farm were silage-only hybrids with high fiber digestibility and starch that is fairly vitreous.

This is a preliminary estimate of the fermentation in the rumen. The 7-h time point is a suggestion from Allen at Michigan State. His suggestion is based on his studies in high producing cows that have been ruminally and duodenally cannulated. We are beginning to use this approach in formulating rations. This is having an impact on how we formulate rations.

Below are some very tentative guidelines to formulate rations for fermentable carbohydrate. Understand that we have not, until now, had a means to measure starch fermentability. We still have some concerns about particle size of the sample and the repeatability of the *in vitro* assay. Also understand that we are still very much in the beginning stages as to where we need to be for the guidelines.

Table 4. Tentative starch and starch fermentability for transition and lactating cows

Group	Starch in Ration %DM	Fermentable, % Starch 7h	Fermentable, %DM 7h
Close up	16 to 18	80	12.8 to 14.4
Early lactation	25 to 27	74	18.5 to 20.0
Peak cows	26 to 28	83	21.6 to 23.2
Mid lactation	24 to 26	78	18.7 to 20.3
Late lactation	23 to 25	76	17.5 to 19.0

Table 5 is an example from Nutritional Dynamic System, V3 Professional (NDS Professional, www.rumen.it) on how we might use least cost formulation in the future. This is from the new Italian CNCPS 6.1 platform NDS Professional. When optimizing rations we can now place minimums and maximums on the different carbohydrate fractions according to the guidelines above.

Table 5. Least cost formulation for carbohydrate formulations.

			Level	Min	Max
✓	ME Supply	% Req	100.724	100.000	120.000
✓	MP Supply	% Req	99.739	99.000	105.000
✓	Rumen NH3	% Req	133.197	115.000	140.000
✓	Peptides	% Req	122.203	100.000	140.000
✓	Sugar degr.	% DM	4.123	3.000	7.000
✓	Starch degr.	% DM	21.373	20.000	25.000
✓	CHO B3 degr.	% DM	10.405	10.000	13.000
✓	CHO degr.	% DM	42.049	40.000	46.000
✓	Lys	% MP	7.061	6.900	7.200
✓	Met	% MP	2.358	2.300	2.400

NDS Professional V3, RUM&N Sas, Via Sant'Ambrogio, 4/A - 42123 Reggio Emilia – ITALY

First is the concept of groups. It is appreciated that many dairies have one lactating group or one dry cow group. It also needs to be recognized that there are physiological differences and requirements associated with these groups. Dr. Allen (Allen & Bradford, 2008) has been emphasizing the impact that the liver has on controlling intake. He also has been emphasizing the importance of gut fill as a part of intake regulation. During the transition period (close up and early lactation) there is a need to provide lower fermentable starch with more of the starch being fed escaping fermentation and being digested in the small intestine. This translates into a lower fermentable starch during this period. As the cow moves into peak lactation, it is suggested that this is a period where high amounts of fermentable starch can be used, promoting high propionate production, and high microbial yields. If balanced properly the fermentation will be well coupled with little risk of acidosis. The propionate, a major precursor to lactose production also will affect receptors, controlling intake and improving feed efficiency.

Table 5 provides starch as a %DM. Now we have become comfortable with our recommendations as to the concentration of starch in rations for dairy cows. We have learned, over time, that we can feed higher concentrations in the fall and winter and not have problems, but come spring and summer, we had better cut back on the amount of starch in the ration. If you look again at the two figures above, you will see that there is a change in starch fermentability in corn silage over time.

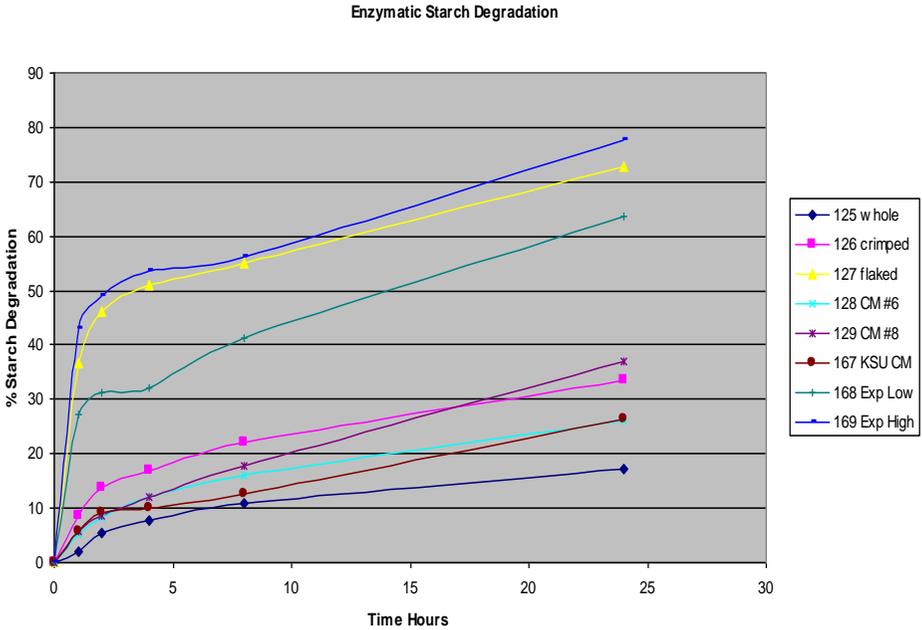


Figure 5. Effect of processing on starch degradability over time. (Hoover & Webster, 1995)

By reducing the starch in the ration in the spring and summer, we are adjusting the fermentable starch to a given concentration in the ration. What this table is suggesting is that we can, now, with measurement of starch fermentability, formulate to an optimum fermentable starch level based on stage of lactation and transition, coupled with our assessment of the environment surrounding the cows and the management of the cows.

Data were presented last fall at the 2009 Cornell Nutrition Conference (Sniffen et al., 2009 and Van Amburgh, personal communication) showing that there are two pools of starch in corn. This fits nicely with the work done by Hoffman at Wisconsin, with the different levels of prolamin protein in corn. Depending on how the corn is processed (high moisture, steam flaked, steam rolled, fineness of grind, DM at ensiling, etc.) and the genetic background – floury to vitreous (low to high prolamin), the corn will have a varying percentage of the fermentable starch disappear in 2 to 3 hours. This is a very high fermentation rate. It is suggested that this is what we need to control. Above are some enzymatic data from measurements made at West Virginia Fermentation Lab in the mid 90’s that demonstrates that there are two pools and that the pool that disappears in 2 hours can disappear very rapidly.

It would appear that the major consideration is what occurs in the first 2 to 4 hours. Our challenge will be to formulate rations that will control the

concentration of this fraction. CVAS is now doing 2 hour *in vitro* starch degradability measurements. It is our hope that we can eventually incorporate this thinking into our nutrition models. For now, we will need to be content with the one pool system and if we get 2-hour measurements as well then we can compare this number with the 7-hour number to make an assessment if a high % of this pool disappears in 2 hours. If a high % of the pool is disappearing in 2 hours then we need to be very cautious in using much of this starch source in close up and early lactation rations. Please understand that this table, at this point, is in the concept stage, but is suggested as an approach we might consider going forward. The bottom line is we need to formulate for rumen fermentable starch, %DM, going forward.

It needs to be pointed out that the starch that is more vitreous, depending on particle size, could also have lower intestinal digestibility. The Wisconsin group provided an assay approach for whole tract digestibility (Blasel et al., 2006; Shaver & Hoffman, 2006). It is obvious from this work that we need to develop a more sophisticated approach to measuring small and large intestine digestibilities.

So how do we formulate rations? For the lactating rations in the spring, we might need to identify some very resistant starch sources for the early lactation cows. In the fall if we have a silo full of vitreous corn, we might need to identify some floury corn, use some steam flaked corn, or possibly introduce some barley, triticale or wheat grains. It is suggested that we need to think differently in putting together the right hand side in the optimization of the fermentable starch in the rations for our cattle.

■ Summary

It was a significant move for us to adapt the concept that the fiber in forages had different fermentabilities based on environment, maturity, and genetics. We are now accepting these ideas and are routinely formulating rations based on these concepts. It should be added that we are still evolving in this area, and not without controversy!

We now are moving into the area of starch fermentability in the rumen. We recognize that there is a large variation but we still lack, until recently, a means to measure this. The 7-h *in vitro* assay of Michigan State offers us a starting place. The addition of a 2 to 4 h *in vitro* starch measurement might improve the sensitivity. In the short run, we are locked into a one pool system with the formulation platforms that we have available to us. Hopefully this will evolve with time.

■ References

- Allen, M.S. and B.J. Bradford. 2008. Optimizing Transition Cow Diets. Proc. Of the Tri-State Dairy Nutr. Conf., Pg 37
- Blasel, H.M., P.C. Hoffman, R.D. Shaver.2006. Degree of starch access: An enzymatic method to determine starch degradation potential of 4 corn grain and corn silage. *Animal Feed Science and Technology* 128: 96–107
- Correa, C. E. S. R. D. Shaver, M. N. Pereira, J. G. Lauer, and K. Kohn. 2002. Relationship between Corn vitreousness and ruminal in situ starch degradability *J. Dairy Sci.* 85:3008–3012
- Hoffman, P.C. and R.D. Shaver. 2009. A Guide to Understanding Prolamins. Department of Dairy Science University of Wisconsin-Madison
- Huntington, Gerald B. 1997. Starch Utilization by Ruminants: From Basics to the Bunk *J. Anim. Sci.* 75:852
- Larson, J. and P. C. Hoffman. 2008. *Technical Note: A Method to Quantify Prolamin Proteins in Corn That Are Negatively Related to Starch Digestibility in Ruminants.* *J. Dairy Sci.* 91:4834
- Lopes, J. C., R. D. Shaver, P. C. Hoffman, M. S. Akins, S. J. Bertics, H. Gencoglu, and J. G. Coors. 2009. Type of corn endosperm influences nutrient digestibility in lactating dairy cows. *J. Dairy Sci.* 92:4541–4548
- Shaver, R.D., P.C. Hoffman. 2006. Degree of Starch Access (DSA): Starch Digestibility in Forages and Grains fed to Dairy Cattle *Focus on Forage - Vol 8: No. 3*
- Sniffen, C. J., M. B. de Ondarza, R. Ward. 2009. Interpreting and implementing starch digestibility information in the field. Proc. of the Cornell Nutr. Conf., Pg 148
- Taylor, C. C., and M. S. Allen. 2006. Corn Grain Endosperm Type and Brown Midrib 3 Corn Silage: Site of Digestion and Ruminant Digestion Kinetics in Lactating Cows. *J. Dairy Sci.* 88:1413

