TERRA INCOGNITA: UPDATES ON FEEDING NONFIBER CARBOHYDRATES TO DAIRY COWS (YES, IT DOES MATTER)

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Introduction

In the year 1565, Paolo Forlani drew a map of the known world that showed landmarks familiar to us today: North and South America, Europe, Asia and Africa are readily recognized. However, South America and Australia are attached to Antarctica, North America appears to be connected to Asia, and some of the proportions of the continents or coastlines seem a bit off from what current satellite maps would indicate. Unicorns, rhinoceroses, and camels were shown to inhabit Antarctica. The cartographer was correct in many large details, incorrect in others, and the fine points certainly needed improvement. There were also certain areas of the map that were labeled “Terra Incognita” – which is Latin for “Unexplored Territories”. No one had yet sent back reports from those lands, and so there was no information about them.

Akin to the early map maker, we are more or less at the same state in our knowledge about how the various nonfiber carbohydrates (NFC) fit within our picture of ruminant nutrition. We have a sense of how some types of NFC function within rations, but our knowledge is incomplete, and the area of interactions of the array of NFC with other dietary components has much room for exploration. We know that the NFC are comprised of many different types of carbohydrates including sugars (low molecular weight carbohydrates), starch (alpha-linked glucans), and soluble fiber (pectins, mixed linkage beta-glucans, gums, etc.), but we do not yet have feeding recommendations that take into account their different digestion characteristics or products. Expanding our knowledge base in this area will do much to fill in the gaps in our map.

A Recent Lactation Study

By-product feeds tend to have more variation in their NFC composition than do the grains, which tend to be rich in starch. Which raises the questions: “When you find a good buy on a by-product, or you are trying to supplement a specific type of NFC to enhance the cows’ performance, what performance can you expect relative to animal response to starchy feeds?” and “Should you change how you formulate for other nutrients, depending upon what type of NFC is increased?” Some research has shown

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that the NFC can differ in the microbial protein yield that they support (Hall and Herejk, 2001; Sannes et al., 2002). Should protein supplementation be modified depending upon the NFC source used in a ration?

A recent study completed by Colleen Casey Larson for her Master of Science Degree (Larson, 2003) at the University of Florida evaluated the effects of three different profiles of dietary NFC vs. two levels of bypass protein on lactation performance as well as ruminal and blood measures in 38 early lactation Holstein cows (82 ± 19 days in milk). The study was designed to give a better understanding of how cows would perform if fed byproduct feeds predominating in different NFC, and how protein supplementation might change performance depending upon the NFC fed. The individually fed cows all received similar basal proportions of roughage (25.6% corn silage, 11.7% sorghum silage, 3.9% cottonseed hulls, as % of diet dry matter (DM)). Whole cottonseed (13.5% of DM) and the vitamin and mineral mix (4.2% of DM) were fed at similar concentrations across diets, as well. The three NFC dietary treatments were starch (ST), soluble fiber plus sugar (SF), or sugar (SU), provided by altering the amounts of ground corn (starch), citrus pulp (soluble fiber + sugar), molasses (sugar), and sucrose (sugar) included in the diets. Bypass protein levels of the diets were changed by using 48% soybean meal as the primary protein supplement (-RUP) or substituting a combination of expeller soybean meal (SoyPLUS®; West Central Soy, Ralston, IA) and 48% soybean meal (+RUP) for the soy. All diets were formulated to contain similar concentrations of crude protein, total NFC and neutral detergent fiber (NDF) (Table 1). Although formulated to contain ~17.5% crude protein, the diets contained 0.5 to 2.0% of DM less than that, and did differ in crude protein content across diets, possibly due to undetected changes in feed composition. However, milk urea nitrogen (MUN) was greater than 12 mg/dl across all treatments, suggesting that rumen degradable protein was not likely to be limiting.

Table 1. Measured composition of diets (Larson 2003).

	Diets[1]					
% of DM%[2]	ST-RUP	ST+RUP	SF-RUP	SF+RUP	SU-RUP	SU+RUP
CP	16.4	15.4	16.3	16.2	17.0	16.5
NDF	39.1	39.6	40.7	40.5	38.5	38.1
NDFCP	3.6	4.0	3.8	4.0	3.8	4.0
Sugar	4.1	4.3	7.6	8.0	13.1	13.5
Starch	23.4	23.6	14.8	15.3	13.4	13.0
NDSF	1.9	1.9	5.5	5.3	4.0	3.3
Sum of NFC	29.4	29.8	27.8	28.5	30.5	29.8
Ash	6.4	6.3	6.6	6.5	7.0	6.9

[1] ST = starch (ground corn), SF = soluble fiber (citrus pulp), SU = sugar (molasses + sucrose), -RUP = 48% soybean meal, +RUP = 48% soybean meal + expeller soybean meal.
[2] CP = crude protein, NDF = neutral detergent fiber, NDFCP = crude protein in NDF, sugar = 80% ethanol-soluble carbohydrate, NDSF = neutral detergent-soluble fiber, sum of NFC = sugar + starch + NDSF.

There were differences in the cow responses across NFC, to the addition of bypass protein, and sometimes to the interaction of the two treatments (Table 2). The only significant performance effects of increasing bypass protein feeding were on protein intake and MUN, and these could have been related to the lower than predicted protein content of these diets.

Table 2. Cow intake, production, and blood responses (Larson, 2003).

Response[2]	Diets[1]						
Per cow per day	ST-RUP	ST+RUP	SF-RUP	SF+RUP	SU-RUP	SU+RUP	SED[3]
Intake, lb							
DM	55.1	55.6	52.7	51.8	55.6	54.2	1.7
CP	9.1	8.8	8.8	8.5	9.7	9.1	0.3
NDF	21.2	22.0	21.4	20.9	21.4	21.1	0.8
Starch	12.9	13.3	7.8	7.5	7.3	6.9	0.4
NDSF	1.2	1.1	2.9	2.8	2.2	2.0	0.4
Sugar	2.3	2.3	3.9	3.8	7.3	7.6	0.2
Production and blood							
Milk, lb	90.4	86.2	83.8	85.1	88.4	90.2	2.4
Fat, lb	3.0	2.9	2.8	3.0	3.0	3.1	0.1
Protein, lb	2.5	2.3	2.2	2.2	2.3	2.3	0.1
3.5%FPCM, lb	85.8	81.1	78.7	81.6	84.2	84.9	2.8
Feed efficiency	1.58	1.47	1.51	1.59	1.52	1.56	0.06
N efficiency	0.27	0.26	0.25	0.26	0.24	0.25	0.01
SCC	2.51	2.78	2.23	2.26	2.75	3.25	0.40
MUN, mg/dl	13.6	13.2	13.1	12.1	12.8	12.2	0.6
Glucose, mg/dl	66.0	66.5	65.0	65.3	67.4	66.9	1.0
Insulin, ng/ml	0.52	0.49	0.46	0.47	0.53	0.54	0.04

[1] ST = starch (ground corn), SF = soluble fiber (citrus pulp), SU = sugar (molasses + sucrose), -RUP = 48% soybean meal, +RUP = 48% soybean meal + expeller soybean meal.
[2] DM = dry matter, CP = crude protein, NDF = neutral detergent fiber, NDSF = neutral detergent-soluble fiber, sugar = 80% ethanol-soluble carbohydrate, 3.5%FPCM = 3.5% fat- and protein-corrected milk, feed efficiency = (3.5%FPCM lb)/(DM intake lb), N efficiency = (milk nitrogen lb)/(inkake nitrogen lb), SCC = somatic cell linear score, MUN = milk urea nitrogen
[3] SED = standard error of the difference

NFC effects

- The greatest DM intake was achieved on the starch diet (P = 0.09), and cows offered the sugar diets consumed more than did cows fed citrus diets (P = 0.03).
- Cows produced more milk (P = 0.01) and 3.5% fat- and protein-corrected milk (P = 0.03) on the sugar diet than on the citrus diet. Numerically, responses to sugar and starch diets appeared to be similar.
- Milk protein yield (P = 0.01), feed efficiency for nitrogen (crude protein) (P = 0.03), and MUN (P = 0.02) were greatest for cows fed the high starch diets. Normally, one might expect MUN to be lower for a diet with a greater milk protein yield and feed efficiency for nitrogen.

- Cows fed the sugar diet had a greater milk protein yield than cows fed the citrus diet ($P = 0.06$).
- Butterfat yield and somatic cell linear score were not affected by NFC source.
- Plasma glucose ($P = 0.01$) and insulin ($P = 0.03$) were greater for cows consuming the sugar diets than for those on the citrus diets. The only other study that reports increased plasma glucose related to sugar feeding was that of Ordway, et al. (2002), however, that response showed up only in dry cows at a much lower sugar inclusion level (2.7% of diet dry matter) than used in the citrus (~7.8%) and sugar (13.3%) diets in this study.

NFC x RUP interactions

These really became quite interesting because the direction of the cows' response to the addition of bypass protein depended upon what NFC source they were receiving. Relative to the diets without added bypass protein, when bypass protein was added, cow responses for:

- Milk yield ($P = 0.05$), 3.5% fat- and protein-corrected milk yield ($P = 0.05$), milk fat yield ($P = 0.07$), and feed efficiency ($P = 0.01$) decreased on the starchy diets but increased or remained roughly the same on the citrus and sugar diets.

Other interesting results

For the ruminal measures that were made with cannulated cows:

- For the 30 hour in situ NDF disappearance performed using sorghum silage, the NFC differed ($P < 0.01$) with the sugar diets having the lowest NDF disappearance. The response did not seem to be directly related to ruminal pH. There was an interaction of NFC x RUP: when more bypass protein was added to the diets, NDF disappearance increased on the starch and sugar diets, but decreased on the citrus diet ($P < 0.01$). These results are in contrast to the findings of Heldt et al. (1999) that showed greater NDF disappearance with diets containing sugar than with starch when rumen degradable protein was not limiting. The present study supplemented more NFC than did the study by Heldt et al. A matter of the amount of NFC provided for what relative effect is seen?
- The ruminal pH across diets did not differ, likely because of the scatter (variation) in the data. However, the sugar diet without RUP gave a numerically lower pH across most sampling hours than did the other diets.
- Ruminal concentrations of acetate were greater on the citrus diets than on the sugar diets ($P = 0.08$).
- Ruminal propionate did not differ across diets.
- Ruminal butyrate was lowest on the starchy diets, greatest on the sugar diets, with the citrus diets being intermediate ($P < 0.01$). This is the same order as the amount of sugar intake measured on the diets.
- Branched chain fatty acid results were the reverse of the pattern for ruminal butyrate, with the lowest values on the sugar diets, and greatest on the starchy diets, and the citrus diets being intermediate ($P = 0.01$). These particular fatty acids are needed by microbes to make amino acids from ammonia. Fiber digesters require them.

- Amino acid concentration in the rumen was lowest on the starchy diets as compared to the other NFC ($P = 0.05$). Whether this is a matter of reduced release or increased use of amino acids by ruminal microbes on the starchy diets is unknown.
- Ruminal ammonia concentrations did differ between protein treatments in the first three hours of the fermentation (-RUP > +RUP; $P < 0.01$), but did not differ among the NFC. This is in contrast to the differences in MUN noted among NFC treatments. Does this mean that, depending upon the NFC source, that different amounts of absorbed protein are broken down to yield more urea nitrogen? Related to the yield of different types of nutrients based on NFC in the diet?

So?

- Protein supplementation may need to vary by NFC source? Based on production responses here and on results of other studies (Hall and Herejk, 2002; Sannes et al., 2003), it appears that starch may yield more protein usable to the animal than the other NFC, at least under the conditions tested. The increase in milk yield and efficiency when bypass protein was added to the sugar and citrus diets suggest that perhaps the protein needs of the animal were being better met with bypass protein added to these diets – less microbial protein from these NFC?
- That the 30 hour in situ NDF disappearance values differed across the diets and did not appear to be strictly pH related suggests that trying to establish or use a single rate for fiber in a feed may not be realistic.
- The differences among NFC in ruminal concentrations of organic acids, amino acids, and in situ NDF disappearance suggest that the NFC fermentations differ from each other in a variety of ways.
- The milk and intake responses in the Larson study differs from the findings of Broderick et al. (2000) that showed linear increases in both with increasing sugar and decreasing starch contents of the diets. The Larson study used up to 13.5% sugar and 23.6% starch, whereas the Broderick study had maxima of 10% sugar and 28% starch (DM basis). We need to find out what the dose responses are to different NFC as other fractions in the rations such as protein and fiber are varied.

Terra Incognita: Food for Thought on NFC In Ruminal Fermentation, etc.

The effects of NFC on production have often been attributed to their relatively greater digestibility than fiber, and their effects on ruminal fermentation often related to pH effects. No doubt that these do play a part in generating the results we see. However, there are a number of results from the study described above and other NFC studies that we cannot explain with our current knowledge base. Below are some thoughts for the future on avenues to explore to get a better handle on how the NFC function in ruminant diets, and how we can better use them in formulation.

Asynchrony vs. Synchrony.

For years, ruminant nutritionists have discussed synchronizing carbohydrates and protein based on their rates of fermentation in order to enhance ruminal fermentation (Johnson, 1976). While good in concept, the overall results of attempted synchronization have not been particularly successful. Let's look at the situation in a different way: 1) fermentation of carbohydrates drives microbial demand for nutrients (nitrogen, branch chain volatile fatty acids, etc.), 2) those demands are not uniform over time depending in part upon rate of carbohydrate fermentation. Could yield of microbial protein be enhanced if the times of peak demand for potentially limiting nutrients were displaced from each other in time so nutrients didn't become limiting? If carbohydrate sources with different rates of fermentation peak in microbial mass and nutrient demand at points more distant from each other in time, the competition for nutrients among the microbial populations might be minimized because there wouldn't be the same draw on the nutrient supply at any given point (Figure 1). We can probably accomplish this by selecting feeds with different rates of carbohydrate fermentation as well as using multiple time per day feeding. Additionally, if a rapid carbohydrate fermentation peaks and starts to decline from substrate depletion before another slower carbohydrate fermentation peaks, the microbes fermenting the more slowly degrading substrate may get the benefit of breakdown products (ammonia, amino acids, peptides, branched chain volatile fatty acids) from the lysis and death of some microbes from the faster fermentation. Having the fermentations of carbohydrates peak at different at different points may also keep ruminal pH more neutral as the production of acids is extended over time.

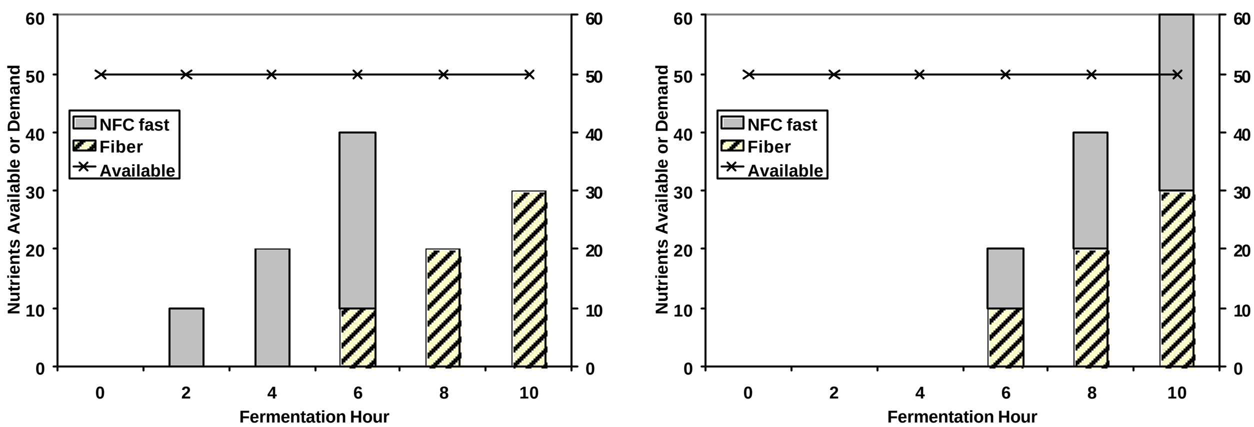

Figure 1. Relative demands for nutrients and nutrients available to meet microbial needs when rates and times of peak carbohydrate fermentation are offset (left) or similar (right). Bars represent microbial demand, line represents available nutrients.

The reports of supplementation of sugars depressing ruminal NDF digestion when rumen degradable protein was limiting, or enhancing it when degradable protein was not limiting may support this notion of competition for nutrients (Heldt et al., 1999). In that study, when degradable protein was not limiting, NDF fermentation was improved over the responses with starch with the feeding of sugars. The sugar fermentations should peak before starch fermentation, with starch fermentation possibly achieving its peak closer in time to the peak of the NDF fermentation. Increasing the amount of sugar in a fermentation can increase the lag time of fiber fermentation

(Weimer and Hall, 2002). Was the lag time for fiber extended because of competition for nutrients among microbial populations with the NFC microbes out-competing the fiber utilizers, or is there some other mechanism causing it?

Inhibitors

Lest we forget, there are factors other than pH, NFC type, and nutrient supply that affect the outcome of fermentations. Piwonka and Firkins (1996) reported a proteinaceous inhibitor of fiber digestion that was produced during the fermentation of glucose.

Monosaccharide Basis & Different NFC Sources

Not all carbohydrates are created equal, particularly from a mass balance point of view. This matters, not just academically, but for predicting what amount of products microbes will make from the amount of carbohydrate provided to them. If we agree that part of the basis for how much product microbes can produce is related back to how much fermentable carbon is available to them, glucose certainly isn't equal to starch. Why? Glucose is a simple sugar, a monosaccharide. Starch is a polysaccharide, it is an extended chain of simple sugars. To form that chain, each sugar loses a molecule of water when it bonds with the next sugar. To put them on an equal basis for what they might be worth to the microbes, you can put the starch on a monosaccharide basis – that means adding back in the weight of water that was lost for the polysaccharide to be formed. For example, on a DM basis, 1 lb of glucose = 1.00 lb of monosaccharides, whereas 1 lb of starch = 1.11 lb of monosaccharide, and 1 lb of sucrose or lactose, which are disaccharides, = 1.05 lb of monosaccharides. If microbes are working from a carbon or monosaccharide basis for their yield of products, a pound of starch will give them more substrate than a pound of glucose will. Although I think that working from a monosaccharide or carbon basis will help our predictions of fermentation product yield, we should not forget that there are differences among the fermentation characteristics of the different mono-, di-, and polysaccharides that will have to be factored in.

Which brings up another issue: ration formulation programs will have to define what basis the carbohydrate is on. For example, weight of dry matter from a specific type of NFC in the diet, or total sugars as invert (a monosaccharide basis used with sugar sources such as molasses)? The basis we use will alter the equations we use.

Summary

We have a fair amount of information on the variety of nonfiber carbohydrates and how they function in ruminant diets. They do differ, in fermentation and digestion characteristics and can affect lactation performance and animal health. We do have substantial areas of "Terra Incognita" regarding NFC that we need to explore before we can set more objective, reliable guidelines for their formulation in rations.

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