

HOW SHOULD WE FORMULATE FOR NON-NDF CARBOHYDRATES?

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Introduction

The non-neutral detergent fiber carbohydrates (NFC) are an important source of energy used to meet nutrient requirements of high producing cows. However, not all NFC sources support similar production performance. Some sources, notably starch, have been associated both with the potential for high production and with problems related to ruminal acidosis (Sutton et al., 1987; Nocek, 1997) which leads to impaired health and performance. Understanding how the array of carbohydrates in NFC fit within the total ration picture, and how they differ in the nutrients they supply to the animal, will offer a better sense of how we should consider them in ration formulation.

Four general categories of NFC are organic acids, sugars (mono- and oligosaccharides), starch, and neutral detergent-soluble fiber. Organic acids, particularly those from fermented feeds, may be utilized by the animal, but do not support appreciable microbial growth. The sugars tend to ferment very rapidly. Except for some of the oligosaccharides, they can be digested by mammalian enzymes, and the resulting monosaccharides absorbed by the animal. Starch may be digested both by microbes and by the animal, but there can be great variation in rate of fermentation or digestion depending upon the processing, storage method, or plant source of the starch. Neutral detergent-soluble fiber includes pectic substances, (1→3)(1→4)-beta-glucans, fructans, and other non-starch polysaccharides not included in neutral detergent fiber (NDF). Soluble fiber tends to ferment very rapidly (20-40%/h), except for that in soyhulls (~4%/h). These carbohydrates cannot be digested by mammalian enzymes, and must be fermented by microbes to be digested. Sugar, starch, and fructan fermentations may yield lactic acid, and tend to yield more propionate than acetate. Pectins, which usually predominate in soluble fiber, tend to yield more acetate. Other than organic acids, the variety of NFC types have been considered to give similar yields of microbial protein when pH is relatively neutral and fermentation rates are similar.

Animal Performance

The performance of lactating cows fed various types of NFC differs among NFC types. Lactating cows fed diets that contained a greater proportion of by-product feeds (citrus pulp, beet pulp) that contain more soluble fiber and sugars, as compared to those containing more starch (from corn products), had lower intakes (Solomon et al., 2000), decreased milk protein % and yield (Leiva et al. 2001, Mansfield et al. 1994, Solomon et al., 2000), and increased butterfat % (Leiva et al. 2001, Mansfield et al., 1994) (Table 1). Mertens et al. (1994) compared the efficacy of carbohydrate sources in utilizing

Table 1. Lactation studies comparing starch and soluble fiber sources.

| | Mansfield et al., 1994 | | Solomon et al., 2000 | | Leiva et al., 2001 | |
|-----------------|------------------------|-----------|----------------------|--------|--------------------|--------|
| | Corn | Beet Pulp | Corn | Citrus | Hominy | Citrus |
| DM Intake, lb | 47.4* | 44.8* | 46.1* | 44.8* | 47.2 | 46.1 |
| Milk, lb | 71.0 | 70.3 | 78.3 | 76.3 | 72.3 | 69.0 |
| Fat % | 3.64* | 3.82* | 3.33 | 3.38 | 3.43 | 3.54 |
| Fat lb | 2.60 | 2.67 | 2.60 | 2.56 | 2.47 | 2.45 |
| Protein % | 3.01* | 2.90* | 3.00* | 2.93* | 2.83* | 2.71* |
| Protein, lb | 2.14* | 2.03* | 2.31† | 2.23† | 2.05† | 1.87† |
| Milk N/Intake N | 0.24x | 0.25x | 0.31x | 0.29x | 0.24† | 0.22† |

* $P < 0.05$, † $P < 0.15$.

x = calculated from data in paper.

alfalfa silage non-protein nitrogen (NPN), with cows fed diets containing 19% citrus pulp + 19% high moisture shell corn, or 39% high moisture shell corn (% of diet dry matter), with or without supplementation with expeller soybean meal. The cows on the citrus diets showed greater milk and protein yield responses to supplemental rumen escape protein than did cows on the high moisture corn diets, suggesting a poorer efficacy of NPN utilization with citrus.

In diets where sucrose was substituted for starch (0 to 7% of diet dry matter as sucrose or pure corn starch, diet NFC \approx 43% of DM; Broderick et al., 2000), there were increases in dry matter intake (+3.3 lb), milk fat content (+0.35%) and fat yield (+0.40 lb) (Figure 1), and milk / dry matter intake decreased from 1.60 to 1.52. Fat-corrected milk production tended to increase (+7.5 lb). The efficiency for conversion of ration nitrogen (N from crude protein; CP) to milk protein N declined linearly with increasing substitution of sucrose for starch (from \sim 0.31 to \sim 0.29; G. Broderick, personal communication). In another study, when sucrose was substituted for corn meal at 1.5% of ration dry matter, intake, milk yield, and fat-corrected milk yield did not change, but milk fat yield increased from 2.12 to 2.14 lb per day, and milk protein % decreased from 3.51% to 3.28% (Nombekela and Murphy, 1995).

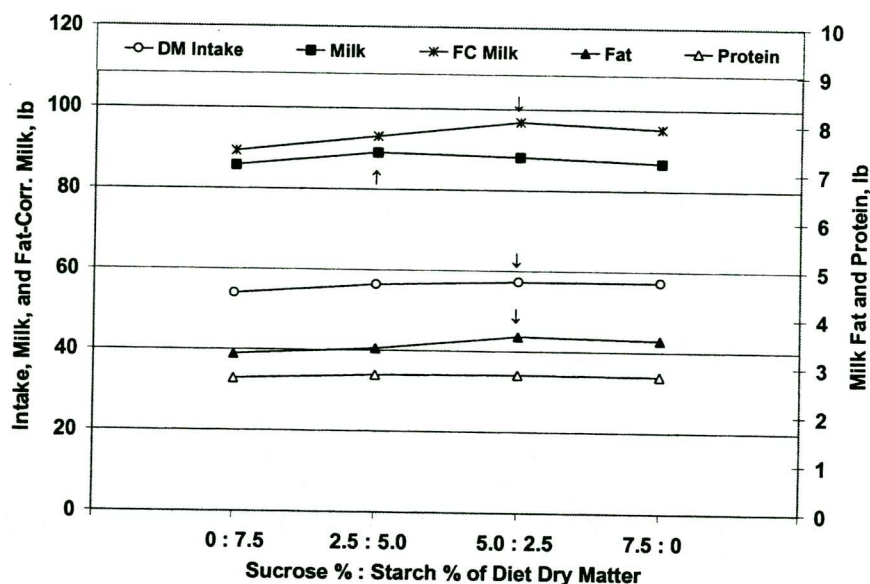


Figure 1. Changes in milk yield and composition with changes in sucrose and starch supplementation. Arrows indicate maximum values. (Broderick et al., 2000).

It appears that altering the proportions of sugars, starch and soluble fiber in rations can alter intake, milk yield and composition, and feed efficiency. However, these studies did not all report the total amounts of the various NFC in the ration. That becomes an important element if we are to understand what amounts of dietary sugars, starch or soluble fiber fed under what conditions optimize performance.

Protein Yield and NFC

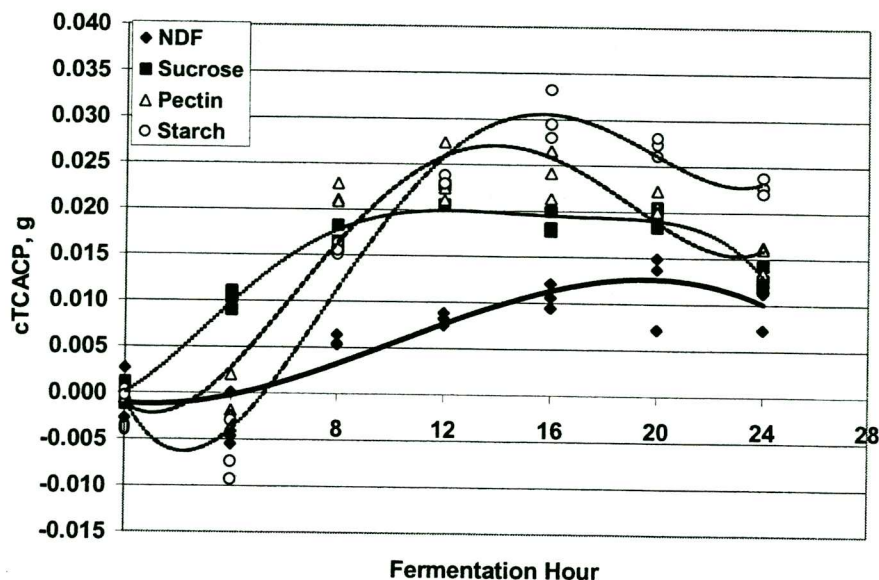
The apparent decreases in milk protein or efficiency of crude protein (CP) utilization noted from soluble fiber or sugars in the above studies are perplexing. Both soluble fiber and sugars tend to ferment very rapidly in the rumen and should support good microbial growth if ruminal pH is not very acidic. Currently, the Beef NRC (1996) and some nutritional models (Russell et al., 1992) predict similar yields of microbes from NFC fermented in the rumen, when the substrates ferment at similar rates. Sugars and pectin (soluble fiber) are predicted to offer the greatest yields among the NFC because of their rapid rates of fermentation. That seems to conflict with the decrease in CP feed efficiency and milk protein yields noted with soluble fiber and sugars as compared to starch.

In a study designed to examine the microbial yield from the different NFC, isolated bermudagrass NDF (iNDF), and blends of sucrose, citrus pectin, or corn starch and iNDF were fermented in vitro (Herejk and Hall, unpublished). The CP, not including non-protein nitrogen or peptides, was precipitated with trichloroacetic acid from samples of each type every 4 hours over two 24-hour fermentations. The CP content of the precipitate plus remaining sample residue was measured, and corrected for fermentation blanks and the original CP content of the sample. All CP information was evaluated relative to organic matter (potentially fermentable material) content. The results show that the maximal yield of CP was greatest from the starch fermentation (32.5 mg), and lower, but similar between pectin (28.1 mg) and sucrose (27.6 mg). If the lower yields of CP from the fermentations of sucrose and pectin translate to reduced amino acid amounts available to the cow, it could explain the reductions in milk protein in the animal feeding trials. For pectin, it could explain the lower efficacy of NPN utilization, and the response to feeding rumen escape protein.

The patterns of CP yield across time also differed among fermentations (Figure 2). Pectin appeared to have a short lag, fermented rapidly, peaked before starch, and then began to decline. Starch had the longest lag of the NFC, and peaked after pectin. Note that, among the fermentation products, microbial mass including protein is the one that is readily produced and degraded in the rumen. The rising portion of the curves likely indicates greater synthesis than degradation of microbial CP before the substrate becomes limiting, while degradation dominates in the declining portion of the curves (see Wells and Russell, 1996).

Sucrose fermented most rapidly initially, and then plateaued. The rapid fermentation and then plateauing of the sucrose fermentation may be explained by the ability of bacteria to store sucrose and other carbohydrates (glucose, fructose, maltose,

Figure 2. TCA-precipitable crude protein yield curves from the fermentation of isolated bermudagrass NDF, and 60:40 blends of the NDF and sucrose, citrus pectin, or corn starch. Data from one fermentation. (Herejk and Hall, unpub.).



cellobiose, fructans) as microbial glycogen (Thomas, 1960; Lou et al., 1997). Microbial glycogen is an alpha-linked glucan, meaning that it is composed of glucose, and has molecular linkages similar to starch, but it is not crystalline. It will analyze as starch. Storage of sugars as glycogen appears to be a survival mechanism for microbes to store food for periods when no more sugar is available. When sugars are depleted, microbes shift from rapid growth and glycogen storage, to maintenance and glycogen use (Lou et al., 1997; Thomas, 1960). So, not all sugars are necessarily converted to microbial mass, organic acids, and gas, but some may pass to the small intestine in the form of microbial glycogen. Even on all forage rations (e.g., hay), there can be a significant flow of alpha-linked glucan to the small intestine (Branco et al., 1999). Thus, microbes are capable of converting one type of carbohydrate into another, and this can change the metabolizable nutrients available to the cow.

Ration Formulation

The obvious question now is: "How should we formulate for NFC?" Darn good question. In an attempt to examine this issue, sugar, starch and soluble fiber contents of dairy cattle rations were calculated for rations obtained from a survey of U.S. rations that supported high milk production and good health. Assurances were offered that what the cow consumed resembled what was on paper, the feeds' proportions of ration dry matter could be calculated, and feed analyses were available (Hall, unpublished). The NFC type values for feeds were estimated using the calculated NFC values (100-CP-NDF-EE-Ash), and the proportions of NFC as sugars, starch and soluble fiber from feed analyses previously performed in our laboratory (Hall, 2000). Some of the results of the survey are shown in Figures 3 and 4. Animal health can be affected by the types and amounts of NFC fed relative to amounts of forage/effective fiber in the ration, so NFC vs. forage values were compared. Soluble fiber was relatively constant across forage and adjusted forage (corn silage minus its starch content) levels. Starch and sugar contents varied inversely. As forage content of the diet increased, starch

Figure 3. Estimated sugars, starch, and NDSF (soluble fiber) relative to the forage in the diets all as % of diet dry matter. (Hall, unpublished).

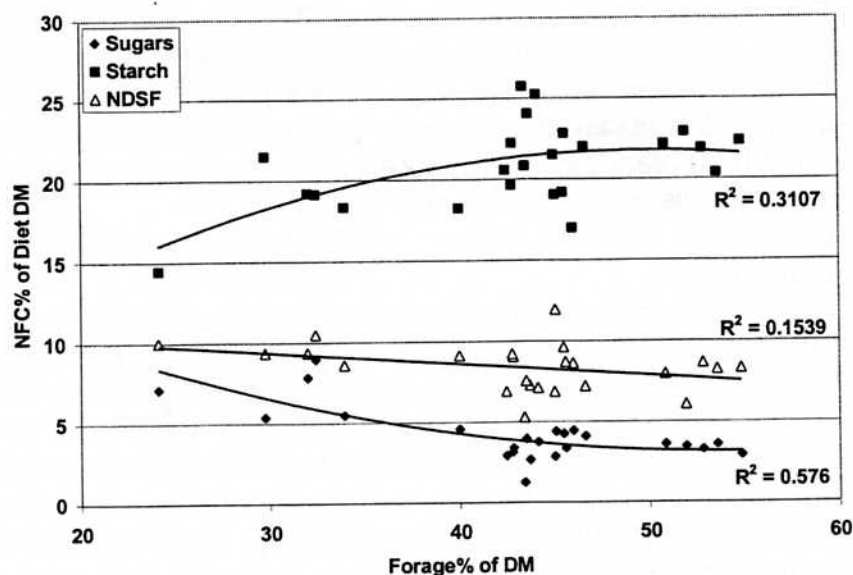
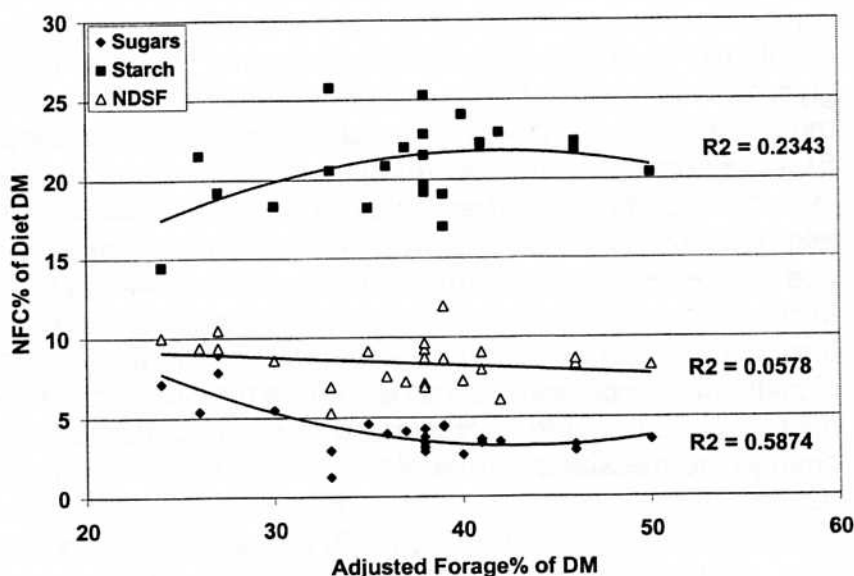


Figure 4. Estimated sugars, starch, and NDSF (soluble fiber) relative to the adjusted forage (corn silage minus starch from corn silage) all as a % of diet dry matter. (Hall, unpublished).



increased and sugars decreased. **HOWEVER**, those changes may be a function of feeds that were available, rather than achieving optimal rations. On the low forage diets, citrus pulp which contains high levels of sugars (26%) and soluble fiber (33%) was included in the rations. Beyond citrus pulp, almond hulls, candy waste, some bakery waste, and molasses, there are not many sugar-rich feed sources available, but starch sources are abundant.

Possibilities To Consider:

- ◆ Pectins/Soluble Fiber: If they yield less microbial protein, inclusion of a greater proportion of rumen escape protein in the ration may be appropriate.
- ◆ Sugars: We do not fully understand what factors in the cow determine the microbe, organic acid, or glycogen yields from sugars in the ration. Again, additional

digestible escape protein may be useful. The sugars may improve palatability and intake.

- ◆ Starch: Appears to offer the highest microbial crude protein yield, however, feeding high levels of starch can lead to ruminal acidosis and digestive upset. We need to find out to what extent sugars and starch are interchangeable to deliver a glucose source to the small intestine, and what proportions of soluble fiber, sugars, and total or effective NDF to include to offset the possibility of acidosis.

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