Considerations for Optimizing Low-starch Diets for Dairy Cattle

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Take Home Message

With the increased input price for corn and other grains that are competitively priced with corn, many dairy nutrition advisors are formulating diets with less than 25% starch. Feeding less than 20%, though, can limit energy availability to support milk production and to support microbial growth (thus milk protein production). Although forages are more competitively priced for energy than in previous years, when forage NDF exceeds 25%, fill restriction is more likely to limit feed intake and milk production. For both reasons, low-starch co-products are being used at increasing inclusion rates. When co-products are providing more than 1% of the diet as free oils, unfortunately there is increasing risk for milk fat depression. Also, although not as filling as forages, fibrous co-products also can restrict feed intake; in contrast, if forage particle size is not long enough for a dense rumen mat, an increasing passage rate of those co-products could limit their fiber digestibility and decrease feed efficiency. Therefore, grain-based co-products should be limited to less than 10 to 15% of the diet if they are high in free oil (especially if an ionophore is fed or in heavy corn silage diets) but can be increased to 25% or possibly more if they are low in fat and have adequate long fiber so long as that fiber is not sorted against. Sugar-based co-products (2.5 to 5.0% supplemental sugar), especially if liquid, can help support rumen fiber digestibility directly or perhaps indirectly through reduced sorting behaviour.

Introduction

In previous years with lower prices for grains, we have pushed high starch diets. Researchers have helped provide guidelines for formulating diets that have a proper ratio of rumen-degraded carbohydrate relative to effective fiber (Zebeli et al., 2010). Nagaraja and Titgemeyer (2007) documented rumen microbial imbalances for cattle with acute acidosis. They also explained why subacute rumen acidosis (SARA) leads to many problems in feedlot cattle even though lactate concentration in the rumen (and blood) only peaks at about < 5% of total organic acids. Canadian researchers have linked bursts of serum virulence factors from low abundance *E. coli* in the rumen (Khafipour et al., 2011). Those workers indicated that these negative populations were more prevalent with SARA from high grain versus alfalfa pellets. However, even beet pulp can promote an overly acidic rumen environment (Lettat et al., 2010). We need to build on past research progress but also consider other factors besides lactate-based SARA to make better potential usage of fibrous co-products. For example, if we are going to use lower starch diets, a logical extension is to maximize digestibility of that starch; if we feed highly processed grains, slug feeding still could promote intermittent problems even if SARA is lessened. I am a proponent of a model that even intermittent imbalances of starch availability relative to fiber and protein could have a prolonged effect on subsequent colonization of fibrous feedstuffs by efficient microbial populations (Firkins et al., 2008a) and would probably benefit most from managerial practices to spread out meals of highly available starch (Dhiman et al., 2002).

Diets with ≤ 22% starch can work, but managers need to continually evaluate cows for depressed milk production or body condition score (Dann and Grant, 2009). I will discuss the potential for depressed dry matter intake (DMI) or poor feed efficiencies. Many evaluation programs, including the NRC (2001), generally assume a constant "discount" for decreasing digestible energy (mostly from depressed fiber digestibility) with increasing DMI. Therefore, cattle might be actually digesting less energy than what the computer predicts is available. Firkins (1997) explained why negative associative effects can be pronounced with various fibrous co-products, and Grant (1997) documented that these negative effects interact with other dietary variables such as forage particle size. Much of this revolves around the function of the rumen mat.

Finally, in recent years, we have gained a better appreciation for how the rumen microbial ecosystem functions. Starch can be digested in the small intestine if it escapes the rumen, whereas we need to enhance the capacity for ruminal fibrolytic microbes to do their jobs under increasing pressure from fast passage to enhance total tract fiber digestibility. I will describe some mechanisms that I consider to be important with respect to improving efficiency of utilization in low-starch diets because this information should help diagnose and predict individual situations to optimise use of low-starch diets.

The Rumen Microbial Ecosystem

Just a couple of decades ago, we used to describe the predominant rumen bacteria like we did cows: they all had a name. Rather than characterizing a few dozen culturable species, we now know that there are probably a few thousand different species of bacteria and archaea (the latter are the microbes that produce methane). Also, many of the major bacteria that efficiently degrade complex carbohydrates (fiber and starch) are very challenging to isolate in a pure culture, so many are only known by an accession number from a large genetic database. Therefore, we have to rely on after-the-fact detective work using molecular-based microbial profiles and complicated statistical inferences. I will spend a little time on this subject because when we feed the cow, we are feeding a vast network of mostly unknown microbes; my interpretation is that we need to reduce variability in this network to optimize feed efficiency.

Some microbial populations have evolved very efficient enzyme systems and other ecological advantages for themselves and their host, whereas other predominant microbes have evolved various strategies (including producing antibiotic-like proteins) to compete against these efficient microbes in ways that are counter-productive for the animal. Paul Weimer at the US Dairy Forage Research Center has a number of studies documenting differences in bacterial populations among cows fed the same diet, and even complete transfer of rumen contents among cows was only transient. Because these population structures are related to a cow's susceptibility for milk fat depression or for poor feed efficiency, our feeding strategies need to reduce variability within cows over a feeding cycle or among different cows.

Why are balanced microbial populations so important? Rather than the *absolute* abundance of enzymes, surface area typically restricts access by microbes to the complex carbohydrates that we feed. Thus, the *relative* abundance of competing groups of microbes dictates their potential success for initial colonization and subsequent growth (cell division) into the expanding cavity of the *next* meal's (and each successive meal's) ingested feed particle (Firkins et al., 2008a). Several studies with exogenous enzymes lacking cellulase or hemicellulase have improved fiber digestibility probably because breaking down protein exposed more initial surface area to promote a rapid attachment and subsequent colonization. Fibrous co-products generally have less lignin (except for cottonseed hulls and a few other sources) and often are of small particle size, but rates of NDF degradation are in the same range as those for forages (Firkins, 1997). Because those fibrous co-products have very high *potential* NDF digestibility, they are *more* susceptible than long forage to inhibited fiber degradation resulting from fast passage rate, low rumen pH, excessive bioactive fat, or insufficient rumen-degraded protein (RDP), which are the topics of the following sections.

Effective Fiber and the Rumen Mat: An Optimum Range

The negative consequences of insufficient physically effective NDF (peNDF) have been well documented. Although the Dairy NRC (2001) chose to use forage NDF because feed coefficients were lacking for a peNDF system, some current ration evaluation programs use peNDF. Still, these programs lack the ability to parameterize interactions among feedstuffs. By the same rationale that the NRC chose not to provide "adjusted" (discounted) TDN values for individual feeds and only discounted the TDN of the diet, we similarly need to collectively evaluate the NDF effectiveness of the entire diet. Some researchers inserted inner tubes into the rumen of dairy cattle and found that filling the tubes with water, not air, provided the extra inert weight that stimulated rumination. Any particles that are not degraded or passed from the rumen can distend the rumen and stimulate rumination. However, larger particles with more structure take more volume, hold more water, add more weight, and stimulate rumination better than smaller particles. In addition, these larger particles help firm up the rumen mat and allow smaller particles to become more effective.

Many nutritionists have accepted a uniform system such as using the NDF retained on a 1.18-mm screen (Mertens, 1997). However, Dr. Mertens' system was derived based on laboratory procedures that sprayed water or had a rotating motion, thus tending to tip particles to pass through the screens based on the particles' width diameters. In contrast, the Penn State Particle Separator, which shakes horizontally, tends to separate more by length. As Dr. Mertens has pointed out, many hays tend to have a greater length:diameter ratio as the chop length increases (from ~ 3:1 to 10:1). Perhaps this explains why Tafaj et al. (2007) reported that particle length was less important for prediction of rumen pH when corn silage rather than grass silage was the primary forage. Finally, although reducing forage particle length should decrease rumination activity, Dr. Armentano at the University of Wisconsin has shown that forage sorting might actually be reduced in TMRs with forages of shorter chop length. What this all means is that we need to do our best to formulate a diet with systems like this, but we also need to continue to consider how the combination of feeds and the cow influence those formulations.

When forage NDF was replaced with non-forage NDF, I inferred from a regression approach that the substitution of fibrous co-products contributed less to total tract NDF digestibility than did forage NDF (Firkins, 1997). Such a response would be contrary to expectations (i.e., co-products have a greater extent of NDF digestion in Dacron bags inserted in the rumen) until you consider the physical characteristics of those non-forage NDF sources. Michel Wattiaux (University of Wisconsin) developed an intricate system to measure functional specific gravity of forages and noted that silages are already wetted and should have a shorter buoyancy phase retaining them in the rumen compared with a hay of similar forage type and maturity. Using Wattiaux's approach, we showed that most of the fibrous co-products we tested increased functional specific gravity compared with forages of similar particle sizes. These co-products would therefore have a greater propensity to sink to the reticulo-omasal orifice for passage from the rumen in a shorter time than that needed for optimum fiber digestibility. Grant (1997) discussed many interactions with soy hulls, which can increase their passage rate from the rumen up to 2 fold when forage particle size is reduced below a critical level. When using many co-products originating from grains, I would expect a similar response. This means that we need to make sure that we have an adequate base of long forage fiber (i.e., forage peNDF) and that the cow actually eats it (doesn't sort it) to retain co-product fiber so that its actual rumen digestibility increases closer to its potential digestibility. Cows could respond from a situation in which co-products are rapidly passing from the rumen by decreasing feed efficiency (milk energy divided by DMI) through 1) decreased digestibility on a % basis with the same DMI or 2) by maintaining the same intake of digestible energy by increased DMI to compensate for the lower % digestibility. In contrast, cottonseed products are very unique in that they actually become more effective when forage peNDF is decreased (Mooney and Allen, 1997), and their slow passage and digestion rates allow them to maintain a dense rumen mat to maintain rumination and entangle smaller particles that would otherwise pass more rapidly from the rumen (Harvatine et al., 2002). When cottonseed's price jumps and its inclusion rate decreases, we need to be more mindful that the rumen mat is firm enough but not too firm.

There is an optimum response for intake of digestible fiber from co-products (other than whole cottonseed) that depends on two sometimes opposing factors: NDF digestibility in the rumen and DMI. Mike Allen at Michigan State University has published several studies related to forage particle size and rumen fill restriction. When alfalfa silage or grass silage were compared, the alfalfa was better able to meet the increasing demand by high producing cows for increased nutrient supply through enhanced voluntary DMI. Even though the grass was high quality and more digestible than the alfalfa, the alfalfa had a relatively fast rate of passage combined with a relatively fast rate of NDF digestion (Voelker Linton and Allen, 2009). The benefit from reduced fill was greater than the detriment from a slightly lower NDF digestibility. In addition, too much coarse fiber might lessen its ability to help maintain a buffered rumen if we have diets with high peNDF and the starch is highly processed. Storm and Kristensen (2010) developed a model that predicts that excessive intake of coarse particles will compact the rumen mat and impede diffusion of VFA to the rumen epithelial cells for absorption (and removal of acid from the rumen). This concept can be adapted to strategies using co-products. When we add high amounts of fibrous co-products to the dairy ration, 1) we need to make sure that their dilution of starch helps to control rumen pH and improve the rate of fiber digestion in forages but especially in the co-products. Then, 2) we must strive to provide a dense enough mat to slow the passage rate of these fibrous co-products for an optimum NDF digestibility. Finally, 3) we need to make sure that the dense mat and entangled co-products do not limit DMI because of rumen fill. These three factors were considered when we showed that DMI and milk production could be maintained with high inclusion rates of wet brewers grains if we substituted them for a combination of forage and starch (Firkins et al., 2002).

Co-Product Inclusion Rates: Rumen-Degraded Starch

Corn, barley, and other grains are fed to increase NE_L intake to boost production. In today's market, many are striving to maximize the digestibility of starch in high-priced grains while including co-products at rates that are cost-effective. But we need to make sure that we do not decrease starch and increase fibrous co-products too much or that strategy could decrease NE_L intake so much that the proportional increase in NE_L used for the cow's maintenance actually decreases profitability. If we add supplemental fat (or too much fat in co-products), the NE_L would be increased but we could depress fiber degradation, restrict DMI, or promote milk fat depression. Finally, NE_L intake (especially DMI) is highly related to microbial protein production, which is critical to support milk protein synthesis.

Feeding excess rumen-degraded starch can depress DMI at least in part by promoting ruminal production of propionate (Allen et al., 2009). When corn processing treatments were compared, steam-flaking corn depressed DMI, but results were inconsistent (Firkins et al., 2001). Barley was more consistent at depressing DMI compared with corn probably because barley starch is much more extensively degraded in the rumen. I should note that barley cultivar likely influences rumen starch digestibility, but these studies help justify why we should be formulating diets for library or laboratory analyses for *rumen-degraded carbohydrate*, not just NFC (the by-difference procedure) or NSC (non-structural carbohydrates measured by enzymes).

Exogenous amylase has been applied prior to feeding to maximize availability of starch in restricted starch diets. A recent report (Ferraretto et al., 2011) discussed variable responses in DMI and feed efficiency among studies. Generally, the enzyme improves feed efficiency, but it might be resulting from decreased DMI compared with a low starch diet without amylase. Because the amylase yields a mixture of short-chain saccharides, the difference among studies might be related to whether or not the amylase-treated product increases ruminal production of propionate (which could decrease DMI) or butyrate (which often results from feeding sugars and should not decrease DMI). More research is needed to sort this out.

Co-Product Inclusion Rates: Rumen-Bioactive Fat

Another way to increase NE_L concentration for dairy cattle while feeding low starch is to feed more fat. Most processing methods for cereal grains disrupt the grain kernel so much that the oil is very readily available. The rapid accumulation of bioactive fatty acids can unpredictably depress milk fat production. A number of studies on distillers grains were summarized by South Dakota State University researchers (Schingoethe et al., 2009). They suggested that up to 30% dry distillers grains or 20% wet distillers grains could be fed. Although their studies support these suggestions, I would comment that I do not endorse such high inclusion rates for field settings because of the large amount of free oil, and I do not subscribe to the notion that wet by-products limit DMI, anyway. Feeding 3% free oil (30% distillers grains x 10% oil) is, in fact, very likely to depress milk fat in field situations because of increased variability of co-product composition or TMR composition among group-fed cows and increasing likelihood of interactions that are better controlled in research settings. Regarding the issue of wet versus dry distillers grains, the 2001 Dairy NRC reversed the opinion of the previous edition: "no optimum DM content of the diet for maximum DMI is apparent".

Among several studies demonstrating milk fat depression from free oils, we demonstrated that pelleting whole cottonseed (14.4% of the diet x 20% fat = 2.8% fat from cottonseeds) decreased milk fat by 0.3% units (Reveneau et al., 2005). Because 30% distillers grains should contribute over 3.0% free oil, a 15% inclusion rate would keep free oil to < 1.5% of the diet DM and would reduce the risk for milk fat depression under field conditions. Unless the inclusion rate is < 10%, I recommend monitoring each herd's milk fat until we can better predict milk fat depression.

Our experience is that DMI is maintained when wet co-products are fed on elevated concrete to keep them from being saturated by ground water during the spring and in shaded areas to protect them from sun exposure during the summer. We fed up to 26% wet brewers grains on a DM basis without depressed DMI or energy-corrected milk production (Firkins et al., 2002), and those diets averaged about 45% DM. We are doing a trial currently with a wet corn-based co-product that is processed to be much drier to reduce transportation costs of dry material. This product has most of the fat extracted to avoid complication previously discussed and thereby can be fed at higher inclusion rates (20 to 30%). Increased inclusion rates of the co-product add formulation incentive for more corn silage to keep from feeding excess protein that would occur with higher inclusion of alfalfa; however, as will be discussed later, corn silage has more issues with milk fat depression than hays or hay-crop silages. If there is difference between wet versus dry co-products, it might be resulting from a coarser particle size if the wet co-product is not tumbled and physically decreased in particle size. Some studies with dried corn gluten feed increased DMI (Firkins et al., 1991), which probably is a result of small particle size and decreased retention in the rumen mat compared with the coarser wet product.

Most of the published studies with high inclusion rates of distillers grains have not used an ionophore in the diet. Our experience with ionophores is that the risk for milk fat depression is minor unless there is high corn silage combined with increased starch and unsaturated fat in the diet. If there is milk fat depression, an improvement in feed efficiency when calculated as milk production/DMI might be lost if converted to fat-corrected milk production. Of course the NE_L from fat goes somewhere, so several studies have shown that minor milk fat depression can increase body condition score and potentially improve energy balance and fertility. When using an ionophore, dairy nutrition advisors need to avoid excessive free oil from highly processed grains and consider free oil from all feedstuffs, not just distillers grains. With respect to the potential for ionophores to interact with co-products containing significant free oil, there has been little research compared with studies with supplemental fat sources, but the same rules should apply compared with other more typical forage-grain diets.

Sugars, Ruminal pH, Fiber Digestibility, and Rumen-Degraded Protein

Both the % of starch in the diet and the rumen degradability of that starch are additive in increasing acid concentration in the rumen (Lechartier and Peyraud, 2010). From results of our meta analysis (Firkins et al., 2001), I have calculated that an increased total tract organic matter digestibility from a more rigorous processing treatment (e.g., steam-flaked versus conventional ground corn) could provide enough NE_L for 1 to 2 kg of extra milk, assuming DMI was maintained (which might not occur, see previous discussion) and fiber digestibility was not depressed because of excessive fermentability in the rumen. Certainly, high feeding rates of sugar would cause SARA, but if sugar is included at a moderate rate, I will explain why it might actually stabilize rumen pH and improve fiber digestibility.

Many, but not all, studies with sugars show increased molar proportion of butyrate or valerate (Heldt et al., 1999). A recent molecular analysis of rumen contents from feedlot beef steers (not fed sugars) documented that those with improved feed efficiency had increased butyrate and valerate concentrations (Guan et al., 2008). Danish researchers have documented that these volatile fatty acids (VFA) are more important fuel sources for the rumen epithelium than are acetate or propionate. For sheep fed the same acidosis challenge diets, some sheep had increased rates of

VFA absorption from rumen epithelia samples than samples collected from other sheep (Penner et al., 2009). Those sheep that had better protection against low pH also had faster absorption rates of VFA (plus protons). More research is needed, but production and absorption of butyrate or valerate could stimulate rumen papillae surface area and thereby increase the rates of acetate and propionate absorption into blood, thus removing these acids from the rumen. Increased molasses feeding increased ruminal pH, and the response was attributed to increasing butyrate increasing the flow rate of blood draining the rumen to pull more VFA absorption into blood (Martel et al., 2011). This premise was supported by butyrate infusion and blood flow measurements parameterizing a VFA absorption model (Storm et al., 2011).

In our study (Oelker et al., 2009) and several others we or Martel et al. (2011) cited, feeding less than 5% sugars rarely decreased ruminal pH and often increased it. When 5 cows each were fed a control or a diet with 4.7% sucrose starting on the day after calving, the ruminal pH actually tended to be higher for the sucrose diet, and the time at which pH was below 5.8 was numerically reduced by about 2.5 hours per day (Penner and Oba, 2009). If sugars reduce the time when pH is below a critical threshold and if initially low pH residually limits degradation of newly colonised fiber particles (see earlier discussion), then sugars could improve fiber digestibility. Broderick and Radloff (2004) provided evidence from two trials as well as from other studies that a moderate amount of sugars in the diet can (but do not always) increase NDF digestibility in dairy cattle.

The ability for some microbes to consume lactate and thereby stimulate fiber digestibility by other microbes probably depends on having adequate rumen-degraded protein (RDP). A comprehensive metagenomics study confirmed the importance of *Megasphaera elsdenii* and various *Prevotella* species to help maintain a healthy rumen (Khafipour et al., 2009). These predominant starch- and sugar-using bacteria produce a steady supply of amino acids and branched chain VFA, and both of these stimulate fibrolytic bacteria (Walker et al., 2005). When beef cattle were dosed with pure starch or glucose, lactate only spiked after feeding glucose, and there was a corresponding prolonged butyrate concentration, indicative of a stimulation of a butyrate-producing population (Arroquy et al., 2004b). Protozoa and bacteria that use lactate as an energy source can increase butyrate or valerate production. In a companion study, lactate concentration again spiked when glucose was dosed at an equivalent concentration as starch, but lactate concentration decreased incrementally back to baseline with increasing supply of RDP (Arroquy et al., 2004a). Thus, having adequate RDP might be a prerequisite for allowing the bacterial populations that use glucose or lactate as substrate to "buffer" the ruminal fermentation from bursts of low pH, with the caveat that adding RDP would only be beneficial if peptide concentration is indeed limiting. Because of uncertainty in the latter, unfortunately we need to feed enough RDP for the average cow but also a small safety factor for those cows that benefit unpredictably from having more RDP. When we formulate for the average cow or take an average response from multiple studies when applying that information to field situations, we add risk for negative responses when the particular field situation is not "average" anymore.

Rumen-degraded protein does not just provide peptides for bacterial growth; it also is continually degraded to ammonia, the main N source for cellulolytic bacteria. In our study (Oelker et al., 2009) and others we cited, adding molasses decreased ruminal ammonia concentration. Adding urea to corn silage diets recovered ammonia concentration to that of the control, but when we fed alfalfa hay (high in RDP that is not ammonia), molasses did not influence ruminal ammonia concentration. The linear decrease in ammonia concentration with increasing sucrose substitution for starch without an increase in microbial N production is consistent with these responses (Broderick et al., 2008). The net concentration of ruminal ammonia depends on its production from RDP and transfer from blood urea N relative to its incorporation into microbial protein. Thus, a net decrease in ammonia concentration can be a sign of more efficient microbial protein synthesis that could be limited by peptide supply, not necessarily by ammonia concentration.

The CNCPS and CPM models focus on providing adequate ammonia concentration for the cellulolytic populations but focus on peptide supply only for the NSC bacteria. However, cellulolytics work in a consortium and benefit from preformed amino acids directly or indirectly (Walker et al., 2005). The lack of interaction between the fibrolytic bacteria and the NSC bacteria in CNCPS/CPM systems might underestimate the need for peptides and require more empirical consideration by the nutrition advisor to force constraints. Insufficient RDP occasionally limits DMI by up to 1 kg/d even though the average response is less (Firkins et al., 2006). I infer from these studies that the hidden decrease in DMI among random herds decreases our ability to repeatedly formulate diets for RDP below 10% of the DM without risk for lost production. Although some recent studies singularly show otherwise, we need to realize that a limitation in protein supply is less severe than a limitation in DMI, which affects intake of *every* nutrient. Moreover, in low-starch diets, our tendency is to think that less RDP is required to support microbial growth, but our meta analyses show that DMI is by far the biggest driver to support microbial protein flow to the duodenum (the major source of protein for the cow). Finally, I can attest that we have more control over dietary situations in research trials than in the field. If researchers formulate for crude protein and RDP, we will monitor it to be sure, but in the field, you might not know about this deficiency until you have lost production and potentially a client.

Sugars in Moderate Starch Diets

Sugars are highly efficacious when they can stimulate DMI (Firkins et al., 2008b). Increasing milk lactose secretion probably "pulls" more glucose production by the liver rather than increasing glucose production "pushing" milk lactose synthesis. When propionate supply to the liver exceeds its needs for glucose release to the mammary gland, the propionate then can send a feedback loop to reduce feed intake (Allen et al., 2009). Sugars tend to increase the ruminal concentration of butyrate and valerate, but typically do not affect propionate or might decrease its concentration. For example, when purified corn starch was replaced with sucrose, propionate or butyrate concentrations were not affected, but valerate and the branched chain VFA plateaued at an intermediate sugar concentration (quadratic response; Broderick et al., 2008). Both DMI and milk fat yield increased linearly with increasing sucrose substitution for starch in that study.

The relationship between NSC and milk fat yield probably depends on forage source. Weiss et al. (2009) documented an important interaction between dietary starch concentration and the ratio of alfalfa silage:corn silage for milk fat yield. With increasing alfalfa silage:corn silage, increasing dietary starch concentration tended to increase milk fat yield. However, with decreasing ratio of alfalfa silage:corn silage (i.e., more corn silage), increasing dietary starch above about 25% was associated with decreasing milk fat yield. Krause and Combs (2003) added corn silage to alfalfa silage diets, and the corn silage also increased dietary starch concentration; however, milk fat was not depressed with fine chopping unless corn silage was added. Zebeli et al. (2009) chopped corn silage (kernel processed) to three theoretical lengths of cut (approximately 1.4, 0.8, and 0.1 cm, respectively). The coarsest corn silage probably limited DMI (20.5 kg/d) from bulk fill compared with the other two treatments. The medium silage increased DMI (21.8 kg/d) because, on average, they ate more meals, but those fed the short silage (22.0 kg/d) ate more feed per meal, primarily in the evening. As particle length of corn silage increased, cows linearly increased their preference for particles retained on the 1.18-mm screen as well as those particles passing through that screen but recovered in the pan. Therefore, feed consumption, particle sorting, and rumen function seem to interact with corn silage, so sugars might be more useful in corn silage-based diets if NSC is kept low.

In the study of Penner and Oba (2009), adding dry sucrose promoted selection for the particles recovered in the pan (presumably with a higher concentration of added dry sucrose), especially in the first week after calving. In contrast, in our study (Oelker et al., 2009), adding liquid molasses to the corn silage-based diet increased measured particle size because small particles were conglomerated and therefore not recovered in the pan. However, in another study at OSU with a mix of corn silage and hay, we noted little effect of liquid feeds on sorting behaviour (Eastridge et al., 2011). These two studies corroborate the need for on-farm analyses of particle size and sorting behaviour. Sugars in liquid feeds could allow the use of slightly coarser corn silage to help reduce milk fat depression with less risk of this response being partially negated by differential eating behaviour, especially in group situations. Sugars make diets more acceptable to dairy cows (Murphy et al., 1997), which is consistent with our experience in several trials. Thus, in group-feeding situations, liquid feeds might be more important to 1) reduce sorting for fine particles (through conglomeration) than sorting against coarse particles and 2) increase acceptability to attract cows back to the feedbunk more frequently and thereby spacing out the inter-meal frequency. More work is needed to verify if sugars, especially in liquid feeds, help to reduce variability associated with high corn silage diets, but I would predict a better response with overly dry or coarse corn silages.

OSU Production Responses with Liquid Feeds

We integrated three lactation trials with individually fed Holstein cows fed molasses-based liquid feeds containing different non-protein nitrogen and fat sources (Firkins et al., 2008b). In one of those three trials, when liquid feed was added to diets containing 40% NFC, DMI and milk production were not affected (Table 1). However, when NFC was reduced to 37%, milk fat yield increased and DMI tended to increase when liquid feed was added. When doubling the inclusion rate of liquid feed, DMI increased compared with control unless Rumensin® was added. The ionophore maintained milk fat yield with decreased DMI, and the combination of the ionophore and liquid feed did not depress milk fat secretion. Another trial in that publication showed that adding liquid feeds as the last ingredient of the TMR maintained DMI even when fat also was added, and the combination increased milk fat production.

We just analyzed another trial with liquid feeds replacing corn that was either finely ground or coarsely ground and compared those data to a control with steam-flaked corn (Eastridge et al., 2011). In this trial, though, total NDF and forage NDF were maintained at about 36 and 21%. Cows fed the steam-flaked corn diets had the lowest milk fat yield. Despite the higher butyrate and valerate molar percentages for liquid feed diets, ruminal pH did not increase and there apparently was not enough difference in particle size of ground corn for liquid feeds to interact for milk fat yield. Thus, these data support previous discussions that sugars do not increase the likelihood for milk fat depression, but our expectation to improve milk fat more with addition of liquid feed to coarsely ground corn than to finely ground corn was not realized, probably because starch was dropped too low for coarsely ground corn diets (< 18%). Although we do not have rumen function data and we did not detect differences in cows' sorting behaviour, these results fit with prior discussion that dropping starch below 20% could predispose cows to rumen fill from non-forage NDF and might have negated beneficial responses from liquid feeds.

Table 1. Lactation performance by dairy cattle fed diets containing different concentrations of nonstructural carbohydrates without or with Rumensin®.[1]

	40% NFC		37% NFC				
Item	Control	3.25% LF	3.25% LF	6.5% LF	6.5% LF+R	SE	*P*
DMI, kg/d	23.9[b]	23.9[b]	25.2[ab]	25.9[a]	24.5[b]	0.7	0.08
Milk, kg/d	39.7	39.9	41.6	40.7	40.3	0.9	NS
Milk protein, %	2.93[a]	2.82[b]	2.85[b]	2.85[b]	2.83[b]	0.02	0.01
Milk protein, kg/d	1.16	1.19	1.18	1.16	1.14	0.03	NS
MUN, mg/dL	12.3[bc]	11.8[c]	12.8[b]	13.8[a]	13.5[a]	0.5	0.08
Milk fat, %	3.31	3.42	3.34	3.29	3.31	0.07	NS
Milk fat, kg/d	1.31[b]	1.28[b]	1.39[a]	1.33[b]	1.32[b]	0.03	0.08
BW change, kg/d	0.51	0.28	0.33	0.58	0.46	0.09	0.13
BCS	2.88	2.74	2.95	2.87	2.76	0.07	NS

[1]NFC = nonfiber carbohydrates, LF = liquid feed (Quality Liquid Feeds, Dodgeville, WI), R = Rumensin® (11 g/909 kg; Elanco Animal Health, Greenfield, IN), DMI = dry matter intake, MUN = milk urea nitrogen, BW = body weight, and BCS = body condition score. Data are from Firkins et al. (2008).

[a,b,c]Means in the same row lacking a common superscript differ according to the *P*-value shown if $P \leq 0.10$. NS = not significant ($P > 0.20$).

Conclusions

Dairy rations between 20 and 25% starch provide good opportunities for dietary inclusion of fibrous co-products and sugars. The forages need to be coarse enough to retain the co-products in the rumen longer and maximize ruminal fiber digestibility. However, these longer particles might be more susceptible to depressions in DMI or for enhanced cow sorting. Sugars at 2.5 to 5.0% offer potential benefits that should be considered in low starch diets. In these situations, sugars (especially if provided in liquid feeds) are more likely to stimulate DMI, NDF digestibility, and milk fat production. Adding sugars to diets with Rumensin® does not increase the risk of milk fat depression. Little research has been done with fibrous co-products combined with Rumensin, but they are unlikely to depress milk fat unless they add too much rumen bioactive fat. Although we can use 2 to 3 % unsaturated fat and 2 to 3 % rumen-inert fat (total ≤ 5%) in dairy rations, the amount of free oil should be kept to half or less of the unsaturated fat component to avoid risk of milk fat depression. Because of various interactions for which explanations remain elusive, I have explained specifics to help in troubleshooting unique individual situations.

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Notes