Formulating lactation rations with high-fiber byproducts

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INTRODUCTION

The last decade has brought increased pressure for land use, tighter commodity supplies, and higher cereal grain prices, which have resulted in significantly higher feed costs for dairies. These trends, however, have been accompanied by an increasing supply of high fiber byproduct feeds, many derived from biofuel production. Indeed, an estimated 40% of the corn grain harvested in the United States in 2010 was utilized by the dry milling industry (World Agricultural Outlook Board, 2011).

Other crops are also processed to recover particular fractions of the plant, and in many cases, the fiber component of the crop is of little value for manufacturing. As a result, many byproducts of industrial processing are relatively high in fiber content, making them particularly suitable as feedstuffs for ruminants. Some of the more common non-forage fiber sources (NFFS; ≥ 30% neutral detergent fiber) fed in the United States are wet corn gluten feed (WCGF), distillers grains (DGS), soy hulls, and beet pulp. This article will highlight literature related to feeding NFFS, with the goal of providing nutritionists practical strategies for incorporating these feedstuffs into diets of lactating cows without compromising health or productivity.

FORMULATION STRATEGIES

Traditionally, many nutritionists have emphasized forage: concentrate ratio as a starting point for formulating dairy cattle rations. Unfortunately, this metric is quite imprecise for meeting the nutritional needs of a lactating cow; for example, both corn silage and wheat straw are considered forages, yet they have vastly different chemical and physical properties. These problems become even more obvious when including NFFS, which are high in fiber (like forages) but are rapidly digested and passed from the rumen (like concentrates). In recent decades, most nutritionists have shifted to relying on targeted concentrations of energy, neutral detergent fiber (NDF), protein, and micronutrients. Implicit in either the forage:concentrate or NDF/energy targets is the recognition that productivity of lactating cows is often limited by energy supply (Allen, 2000), yet adequate physically effective fiber is also required to maintain rumen health and milk fat yield.

When incorporating a novel ingredient into a TMR, it is tempting to directly replace an existing component of the diet. Studies have shown it is possible to successfully replace corn grain with soybean hulls (Ipharraguerre et al., 2002) or a combination of soybean hulls and cottonseed hulls (Beckman and Weiss, 2005). In both of these studies, milk fat concentration significantly increased, with few effects on other production parameters. However, it is rare that direct substitution represents the optimal use of such ingredients. This is evident from other trials in which soybean hulls or beet pulp replaced corn grain and decreased milk production (Nakamura and

Owen, 1989; Pantoja et al., 1994) or milk protein production (Mansfield and Stern, 1994; Mansfield et al., 1994).

Many NFFS provide valuable nutrients in addition to digestible fiber, and most often that nutrient is protein. Therefore, it is common that NFFS replace a combination of both cereal grains and oilseed meals in rations (Armentano and Dentine, 1988; Clark and Armentano, 1997; Younker et al., 1998). However, even this more balanced approach to formulating with NFFS can sacrifice productivity because of a decrease in digestible energy supply. Although NDF from NFFS is relatively digestible compared to forage NDF, replacing highly digestible non-fiber carbohydrate (NFC) with NDF can depress feed intake, decrease diet digestibility, and limit milk production (Anderson et al., 2006; MacLeod et al., 1985; Schingoethe et al., 1999; Staples et al., 1984).

More recent experience with NFFS suggests that these ingredients can be utilized most effectively when traditional carbohydrate targets are abandoned, and nonforage NDF is used to replace a combination of forage NDF and starch. These highly digestible NDF sources can supply substantial amounts of ruminally-fermentable organic matter with more constant acid production in comparison to high starch concentrates (Fellner and Belyea, 1991; Stock et al., 2000). They can also replace portions of forage fiber if the physical characteristics of the ration remain sufficient to stimulate rumination (Allen and Grant, 2000).

A series of 3 experiments reported by Boddugari et al. (2001) nicely demonstrates typical responses to these different approaches to NFFS utilization. First, a milling product similar to WCGF was used to replace 0, 50, 75, or 100% of the concentrates in a lactation diet. As indicated above, this replacement of NFC with NDF decreased dry matter intake, although in this case milk yield was maintained, resulting in improved feed efficiency (Boddugari et al., 2001). A second experiment then evaluated partial replacement of forage in addition to the complete replacement of concentrates by the milling product; these 4 diets contained 45, 53, 62, and 70% NFFS (DM basis), with as little as 30% forage in the most extreme diet. As the NFFS inclusion rate increased in this experiment, milk production increased, although without an increase in fat yield (Boddugari et al., 2001). Finally, a third study was conducted to compare a control diet to one with 40% milling product, replacing portions of both the forages and concentrates. This approach to NFFS utilization resulted in a 6 kg/d increase in fat-corrected milk yield, driven by a 20% increase in production efficiency (Boddugari et al., 2001). Indeed, a plethora of information indicates that optimal feeding of NFFS can not only reduce feed costs, but also improve productivity of dairy cattle (Aliyu and Bala, 2011; Ipharraguerre and Clark, 2003; Nadeem and Sufyan, 2005; Schingoethe et al., 2009).

Energy

Rather than focus on specific nutrients as energy sources, many nutritionists simply formulate for a target predicted energy density. However, this approach has shortcomings. Model predictions of energy supply are notoriously imprecise, and such predictions are even less likely to be accurate for NFFS. There are several reasons for this. First, models on which these energy predictions are based were derived from data which generally did not include diets with high inclusion rates of

NFFS. Another problem is that models do not attempt to account for associative effects within diets, which is likely to be a major factor when substantial amount of NFC are replaced by non-forage NDF (Beckman and Weiss, 2005). Finally, one of the more consistent responses to partial replacement of forage with NFFS is an increase in DMI (Kononoff et al., 2006; Mullins et al., 2010; Sullivan et al., 2011), which is not accounted for in models, making energy density predictions less relevant. Therefore, instead of formulating for energy density or starch targets, utilization of large amounts of NFFS requires a more flexible, iterative process.

Experience suggests that the following is an effective approach to formulating diets with high NFFS inclusion rates:

1) Determine a minimum effective fiber concentration to maintain rumen health and milk fat yield. Include forages necessary to meet this requirement, with an adequate safety margin.
2) Incorporate a combination of NFFS and concentrates to provide at least 34% NFC, letting total NDF rise with increasing NFFS incorporation.
3) Evaluate ruminally-available unsaturated fatty acid supply and adjust inclusion rates to limit the risk of milk fat depression (Lock, 2010).
4) Evaluate protein supply, including rumen undegraded protein, metabolizable lysine, and metabolizable methionine supply predictions. Adjust ingredient proportions or add bypass amino acids sources to balance protein supplies.
5) Re-evaluate targets for steps 1-3, then balance for micronutrients.

Using this approach, NDF concentrations may be much higher than in a typical diet, yet because of the high digestibility of the non-forage NDF, such diets can provide adequate ruminally-fermentable organic matter to support high production of microbial protein and volatile fatty acids (Hristov, 2006), and in turn, milk yield (Dann and Grant, 2009). Diets that incorporate more than 20% NFFS can support milk yields in excess of 50 kg/d with less than 22% starch and as much as 37% NDF (Boguhn et al., 2010; Ferraretto et al., 2011; Gencoglu et al., 2010). Many other NFFS-based diets have supported production levels above 35 kg/d with just 25-36% NFC (Batajoo and Shaver, 1994; Boddugari et al., 2001; Kononoff et al., 2006; Miron et al., 2003; VanBaale et al., 2001; Voelker and Allen, 2003).

One significant difference in this approach is that sources of fat will not be formulated into diets because of the lack of focus on energy density. However, this does not negate the utility of dietary fat in some NFFS-based rations. In cases where the ruminal acid load is already high, but more energy is needed to support milk production, adding fat can be a useful way to provide additional energy. In one study, cows fed high-NFFS diets in early lactation outperformed cows fed a traditional diet, but the addition of 2.25% hydrogenated fatty acids further improved productivity (Weiss and Pinos-Rodriguez, 2009). Inclusion of a fat source with limited ruminal availability may allow for further decreases in NFC content of NFFS-based diets, with possible improvements in productivity.

Physically effective fiber

Even though forage:concentrate ratio has little utility, the physical characteristics of the TMR cannot be ignored. Physical characteristics of the TMR have a major impact on chewing activity, which impacts rumen health, DMI, milk fat production, and digestibility (Allen and Grant, 2000). Substituting NFFS for grain will likely have a minimal effect on particle size, but a substitution for forage can greatly reduce mean particle size of the diet. For this reason, nutritionists need to consider physically effective NDF (peNDF) when formulating diets.

There are multiple ways to calculate peNDF, but accepted definitions account for the ability to stimulate chewing, the ability to maintain milk fat concentration and production, or both (Grant, 1997). Thus, peNDF combines information on particle length and chemical content of the diet. Non-forage fiber sources have a small mean particle size, and are typically low in lignin and high in digestible fiber, so including NFFS in diets will decrease the physical effectiveness of NDF. This can be advantageous if ruminal distention is restricting DMI (Allen, 2000) as long as the level of fermentable carbohydrate does not exceed the rumen's capacity for neutralization and outflow of volatile fatty acids.

Despite the theoretical value of peNDF, a field-applicable method for estimating peNDF of a diet has remained elusive. One meta-analysis (Zebeli et al., 2008) demonstrated reasonably strong associations between $peNDF_{>1.18}$ with ruminal pH and milk fat yield. The $peNDF_{>1.18}$ variable is derived by determining the proportion of TMR particles retained on a 1.18-mm screen and multiplying by the total NDF concentration of the diet (Mertens, 1997). Although the meta-analysis suggested that $peNDF_{>1.18}$ is a valuable metric for typical dairy TMR, the database used to evaluate it was not focused on high-NFFS diets. In fact, the mean forage NDF concentration in the database was 21.9% of DM (Zebeli et al., 2008), and NFFS-based diets can contain as little as 12% forage NDF (Harvatine et al., 2002; Miron et al., 2003; Mullins et al., 2010). With such a small proportion of NDF coming from forage sources, using total dietary NDF as a factor in $peNDF_{>1.18}$ calculations is unlikely to result in a useful metric.

A comparison of recent results with low and high NFFS inclusion rates demonstrates this point. Yang and Beauchemin (2007) used primarily traditional forages and concentrates at different proportions and cut lengths to generate diets with a range of peNDF values. One finding from the study was that $peNDF_{>8.0}$ (the proportion of particles retained by a 8-mm sieve multiplied by dietary NDF content) was a far better predictor of ruminal pH dynamics than $peNDF_{>1.18}$ (Yang and Beauchemin, 2007). However, despite having one diet with a $peNDF_{>8.0}$ of just 9.6% of DM, milk fat yield was maintained across all treatments. In contrast, another recent study evaluated 3 diets with WCGF inclusion rates ranging from 33 – 56% of DM, with forage NDF concentrations decreasing from 15.3 to 9.3% of DM (Rezac et al., 2010). Although $peNDF_{>8.0}$ concentrations in these diets remained above 10.7% of DM, the lowest forage diet decreased milk fat yield by nearly 20% and caused clinical acidosis. In this experiment, $peNDF_{>1.18}$ values were even less predictive; $peNDF_{>1.18}$ was greater in the diet that induced milk fat depression than in the control diet (Rezac et al., 2010). Based on these comparisons, it seems clear that peNDF thresholds determined to be safe in traditional rations may not apply to high-NFFS diets. In these examples, milk fat was maintained when forage NDF was 16.0% of DM (Yang and Beauchemin, 2007) or 12.9% of DM, but not when it dropped to 9.3% of DM (Rezac et al., 2010), suggesting that forage NDF should not be ignored in NFFS-based diets.

Unfortunately, there is still no single tool for quantifying fiber adequacy in dairy rations that uniformly predicts rumen health responses to diets. For NFFS-based diets, we advocate an approach similar to that proposed by NRC (2001), using a sliding scale of forage NDF and total NDF concentrations. For example, a minimum of 18% forage NDF is recommended if total NDF content of the diet is just 27%, but only 15% forage NDF is considered necessary if total NDF is 33% of DM. This approach has been successfully extended to 12-13% forage NDF with 31-35% total NDF without inducing milk fat depression (Miron et al., 2003; Mullins et al., 2010; Rezac et al., 2010). This approach reflects the concept that non-forage NDF is approximately half as effective as forage NDF at maintaining ruminal function and milk fat yield (Swain and Armentano, 1994). If these guidelines are followed and diets are prepared such that >35% of particles are retained on an 8-mm sieve (Kononoff et al., 2003), then NFFS diets should support normal rumen function. Wet NFFS can be advantageous for meeting this fiber requirement because they tend to bind diet components together and prevent cows from sorting against longer forage particles (Sullivan et al., 2011).

Despite the importance of effective fiber for dairy cattle, it cannot be forgotten that milk fat depression is a multi-factorial problem. For example, ruminally-degradable starch supply may be an independent risk factor for both decreased ruminal pH (Zebeli et al., 2008) and milk fat depression (Maia et al., 2009). In fact, it's likely that one of the key reasons it is safe to feed high levels of NFFS in low-forage diets is because such diets are typically quite low in starch; we have fed diets as low as 14% starch (Rezac et al., 2010). Secondly, degradability of the forage NDF fraction must be considered as well. Even if recommended forage NDF concentrations are met, NFFS-based diets with very degradable forage NDF (i.e. from brown midrib corn silage) can still result in milk fat depression (Holt et al., 2010). Finally, some NFFS (especially DGS) can provide a substantial load of rumen available unsaturated fatty acids, which is another key risk factor that promotes milk fat depression (Hippen et al., 2010). All of these factors must be considered to formulate a diet that will support acceptable component production.

Protein

Use of NFFS can have a significant impact on protein fractions in a diet. Some NFFS, such as WCGF, provide a highly degradable source of protein, whereas others, such as DGS, tend to provide more rumen undegradable protein, especially if a dried product is fed (Kononoff et al., 2007). These factors can have a considerable effect on diet formulation. For example, if rumen undegraded protein from corn DGS is used to displace a bypass soybean meal product (thereby attempting to maintain metabolizable protein supply), the amino acid composition of metabolizable protein can shift substantially. In such a scenario, it is possible that the first-limiting amino acid can change from methionine to lysine, and supplementing with sources of limiting amino acids can support increased milk protein production (Nichols et al., 1998). Although model predictions of metabolizable amino acid supply are likely imprecise for high-NFFS diets, nutritionists should nonetheless consider adjusting sources of bypass protein if predicted supplies of methionine and/or lysine vary considerably from requirements.

LIMITATIONS AND PRACTICAL CONCERNS

Despite vast differences in the nutrient profiles across individual NFFS, similar nutrition concepts need to be considered as nutritionists incorporate these ingredients into diets. The first and most important thing to consider when incorporating a novel ingredient is the derivation of the feedstuff. Because some byproducts are treated like a waste stream during industrial processing, anti-nutritional factors can easily be introduced. Nutritionists should therefore be knowledgeable of the derivation process to aid in monitoring for potential problems.

Variability

The chemical and physical composition of feedstuffs can dramatically vary across batches. For example, the NRC (2001) reported a high standard deviations for the crude protein (23.8 ± 5.7%) and NDF (35.5 ± 6.8%) concentrations of WCGF. In a Canadian study, Droppo et al. (1985) tested the DM and nutrient composition of 4 samples from each of 14 truckloads of WCGF that had been delivered from a single starch plant. While the range of DM values was wide (40-48%), more concerning was the variability of protein and mineral content between loads; the coefficients of variation ranged from 12 to 35%. Not surprisingly, similar variability has been observed across suppliers for other NFFS (Kleinschmit et al., 2007). The variation in nutrient content likely reflects differences in sources of processing material, or differences in the processing technique for that particular batch. Thus, nutritionists must be conscious of this variation when incorporating these ingredients into diets.

There are approaches to decreasing the risks associated with variable ingredient composition. One approach is to work with a sole supplier that can demonstrate superior product consistency. Although such products often command a premium price, the resulting consistency in the TMR may make the added cost worthwhile. Another common strategy is to minimize the risk associated with any individual ingredient by using a mix of different NFFS sources. For example, Leiva et al. (2000) fed a diet containing 46% NFFS, but this was supplied by 4 different ingredients. The appropriate strategy for a given dairy depends largely on the number and types of NFFS that are cost-effective to purchase in the local area, as well as on the size of the dairy (see below).

Stability

One factor that limits the value of low-inclusion rate NFFS on small dairies is the limited shelf life of wet feedstuffs. Given that dairies often need to accept delivery of a full load of feed to acquire it at a reasonable cost, the farm needs to be able to utilize that load within 4-10 days, especially in warm climates. To increase shelf life, most NFFS can be dried, but this adds substantial cost and largely negates the value of being in close proximity to a source plant. In addition, wet products may be more digestible and support greater productivity in some cases (Anderson et al., 2006).

Although dry products are often the best option for maintaining product stability, other feed preservation strategies exist. For example, ensiling WCGF in a plastic silo bag sustained its quality, as determined by pH, temperature, and organic acid concentrations (Jaster et al., 1984). However, the small particle size of wet NFFS can cause bags to stretch excessively and tear, and the poor flowability of these products can cause problems for upright silos. A potential solution is to blend the NFFS with some other forage and ensile the mixture (Schroeder, 2010). Another approach to preserving wet NFFS is to apply an anti-microbial agent such as propionic acid, which has been successful for short-term preservation (Geetha et al., 2009).

CONCLUSION

Incorporating NFFS into lactating dairy cattle diets provides an opportunity to improve farm profitability through decreased feed costs and possibly increased milk production. Several factors will need to be considered when adding these ingredients to lactation diets, and conventional rules of thumb may not apply when feeding these ingredients in large quantities. Diets formulated to complement the characteristics of any NFFS, rather than a single substitution for an ingredient, will enhance the likelihood of optimizing its use.

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