Balancing Carbohydrate Sources for Dairy Cows during a Period of High Corn Prices

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SUMMARY

• Carbohydrates, NDF and NFC, comprise about 70% of DM in diets for lactating cows.
• While diets containing 21% forage-NDF are common, depending on forage availability, price and quality, diets can be found within a normal range of 16% - 24% forage-NDF (DM basis).
• Maximum NFC guidelines are positively related to forage-NDF content in diets for lactating cows.
• Starch is the major component of the NFC fraction; ruminal and (or) total-tract digestibility of starch varies depending largely on grain type and processing.
• Increased corn prices have created much interest in the potential for feeding reduced-starch diets.
• Feed efficiency and IOFC results from the continuous lactation trials reviewed herein indicate that, for high producing cows in mid lactation, partially replacing corn grain with NDF from either high-fiber byproducts or corn silage to formulate reduced-starch diets was not beneficial.
• Rumensin® increased milk production efficiency when added to both normal- and reduced-starch diets.
• Diets containing about 6% total sugar (DM basis) appear to be optimum.
• Greater extent of high-moisture corn fermentation in the silo increases starch digestibility, apparently through degradation of the starch-protein matrix as reflected by increased ammonia concentrations.

INTRODUCTION

The carbohydrate fraction, which includes neutral detergent fiber (NDF) and non-fiber carbohydrate (NFC), comprises approximately 70% of diets for lactating dairy cows (DM basis). Meeting a minimum forage-NDF guideline is important for providing sufficient physically-effective NDF (peNDF) to support good rumen function, while exceeding a maximum forage-NDF guideline may restrict dry matter intake (DMI) through rumen fill limitation.

When forages are limited and (or) relatively expensive the diet formulations trend toward forage-NDF minimums, while when forages are abundant and (or) are relatively inexpensive the diet formulations trend toward forage-NDF maximums. The Dairy NRC (2001) carbohydrate guidelines reflect a positive relationship between dietary forage-NDF and total NFC, such that the maximum total NFC guideline is reduced for a 16%-forage-NDF diet (38%) compared to a ≥19%-forage-NDF diet (44%; DM basis). This can be accomplished by using a greater proportion high NFC-lower NFC byproduct feed ingredients in reduced-forage-NDF diets, and a greater proportion of low NFC-high NFC grains in higher-forage-NDF diets.

While diets containing 21% forage-NDF (DM basis; i.e. 50% dietary forage with an average NDF content of 42%) are common in the field, depending on forage availability, price and quality, diets can be found within a normal range of 16% (i.e. 35% dietary forage with an average NDF content of 46%) to 24% forage-NDF (i.e. 60% dietary forage with and average NDF content of 40%). In addition to these widely divergent dietary forage-NDF contents, the dietary forage-NDF fraction can vary greatly in peNDF depending largely on particle size and digestibility depending largely on lignin content. Furthermore, the dietary NFC fraction is not homogenous and is comprised of varying proportions of starch, sugars, pectin and organic acids, and also can vary in ruminal and (or) total tract digestibility, at least in the case of starch, depending largely on grain type and processing.

The optimum starch content of diets for lactating dairy cows is not well defined, but 25% starch (DM basis) has been suggested based on a review of published feeding trials (Staples, 2007). Shaver (2010) reported on surveys of high-producing commercial dairy herds performed in Wisconsin and Michigan with dietary starch concentrations averaging 27% and ranging from 25% to 30% in diets containing 21% forage-NDF on average (DM basis). Increased corn prices, however, have created much interest in the potential for feeding reduced-starch diets. Coincident with the interest in reduced-starch diets is a renewed focus on increasing the digestibility of starch by dairy cows. The topics of reduced-starch diets and starch digestibility will be reviewed and discussed in this paper.

REDUCED-STARCH DIETS

Results from published short-term switchback experiments

1Adapted from papers presented at 2012 Southwest Nutrition Conference (Tempe, AZ) and 2012 Tri-State Dairy Conference (Ft. Wayne, IN).
suggest that reduced-starch diets are feasible for lactating dairy cows (Shaver, 2010). Longer-term continuous lactation feeding trials, however, are likely more appropriate than short-term switchback trials for evaluating the effect of reducing dietary starch content on feed efficiency, BW change and income over feed cost (IOFC). Lactation performance responses to reduced-starch diets from five recent continuous lactation experiments will be discussed herein. Four trials were from UW-Madison (UW; Gencoglu et al., 2010; Ferraretto et al., 2011a,b; Akins et al., 2012) and evaluated high NDF-low starch byproduct feeds as partial corn grain replacers, while a trial from the Ohio Agricultural Research and Development Center (OARDC; Weiss et al., 2011) evaluated the partial replacement of corn grain with corn silage. The forage-NDF concentrations were 20%-21% across all diets with 5% to 10%-units less starch for reduced-starch (RS) than normal-starch (NS) diets in the UW trials. For the OARDC trial, forage-NDF concentrations were 23% and 26% for the NS and RS diets, respectively, with 5%-units less starch for RS than NS diets. Across the five trials, the earliest and latest days in milk at trial initiation were 51 and 114 d, respectively, and treatment length ranged from 10 to 14 wk. Milk yield for cows fed the NS diet ranged from 38 kg to 52 kg/cow/d across the four trials.

Dry matter intake was greater for RS than NS in 3 of 4 UW trials (unaffected by treatment in Akins et al., 2012), but lower for RS than NS in the OARDC trial. Greater DMI for RS than NS in the UW trials may be related to reduced ruminal propionate concentration (Allen, 1997; Beckman and Weiss, 2005) leading to increased meal size and consequently greater DMI (Allen et al., 2009). Firkins (1997) suggested that increased digestibility and passage rate of byproduct NDF can allow for increased NDF intake relative to forage NDF, which could explain the difference in DMI response for RS between the UW trials and the OARDC trial. In other words rumen fill likely limited DMI in the OARDC trial (23% to 26% forage-NDF), but not in the UW trials (20% to 21% forage-NDF), where metabolic control of DMI appears to have been more likely (Allen et al., 2009).

Actual milk yield was similar for cows fed RS and NS in 2 of 3 UW trials with soy hulls (SH; Gencoglu et al., 2010; Ferraretto et al., 2011b), was lower (P < 0.01) for RS than NS in the SH trial of Akins et al. (2012), and tended (P < 0.07) to be 4% lower for RS than NS in the UW trial with whole cottonseed (WCS) and wheat middlings (WM; Ferraretto et al., 2011a). Because WCS and WM are moderate-protein ingredients, they partially replaced both corn grain and soybean meal (SBM) in the RS diet. Greater ruminal protein degradation for these ingredients compared to SBM along with reduced rumen microbial protein production for RS may have decreased metabolizable protein flow, which could partially explain the decrease in milk yield (NRC, 2001). Actual milk yield was lower (P < 0.05) for RS than NS in the OARDC trial and was consistent with the DMI response in that trial. Responses for milk yield corrected for concentrations of fat, protein and lactose (solids-corrected milk; SCM) were inconsistent for the UW trials with either greater (P < 0.03; Gencoglu et al., 2010), trend for lower (P < 0.08; Ferraretto et al., 2011b), or similar (P > 0.10; Ferraretto et al., 2011a; Akins et al., 2012) SCM observed for RS compared to NS. The SCM yield was lower (P < 0.05) for RS than NS in the OARDC trial and was consistent with the actual milk yield and DMI responses in that trial. Body weight gain was not different for cows fed RS compared to cows fed NS across the five trials.

Feed efficiencies, across the five trials, were reduced for RS compared to NS by 2% to 12% for Milk/DMI and by 1% to 11% for SCM/DMI. Reduced feed efficiency for dairy cows fed RS diets creates an economic concern for nutritionists desiring to use this formulation strategy to reduce diet cost per unit of DM. Midwest USA December-2011 market prices for feed ingredients and milk were applied to ration composition, DMI and milk production data from the four trials to estimate feed costs and IOFC. Feed costs per unit DM were reduced in 4 of 5 trials by 1% to 6% for RS. Feed costs per cow per day for RS, however, were increased for three trials by 1% to 8% and decreased for two trials by 1% to 7%. Estimates of IOFC were increased in one trial by 2% for RS, and decreased in four trials by 2% to 7% for RS.

Feed efficiency and IOFC results indicate that for high producing cows in early to mid lactation, partially replacing corn grain with NDF from either high-fiber byproducts or corn silage to formulate RS diets was not beneficial. Reduced market prices for high-fiber byproducts relative to corn grain and soybean meal would improve the economics of feeding RS compared to NS diets. Use of higher quality corn silage with reduced NDF content and (or) greater NDF digestibility when partially replacing corn grain with corn silage in RS diets may improve responses compared to the trial reviewed herein, and further research is warranted. Furthermore, RS diets formulated by partially replacing starch with fiber may offer more potential for beneficial responses when fed to lower producing, later lactation cows than evaluated in the trials reviewed herein; potentially less concerns about rumen fill limitations to DMI and milk yield when partially replacing starch with forage NDF or reduced feed efficiency when partially replacing starch with byproduct NDF (Allen, 2008).

Based on the previous UW trial results with RS diets, Akins et al. (2012) hypothesized that Rumensin® would reduce DMI and thus improve milk production efficiency more with RS than NS diets. One-hundred twenty eight cows (90 ± 33 days in milk) were stratified by breed, parity and days in milk, and randomly assigned to one of 16 pens with 8 cows each per pen in the UW-Madison Emmons-Blaine Arlington free-stall barn. Pens were...
randomly assigned to 1 of 4 treatments in a 2 × 2 factorial design (formulated dietary starch content (RS (21%) vs. NS (27%)) and Rumensin® (0 g/ton (Control) vs. 18 g/ton (Rumensin®)) inclusion as main effects) for a continuous lactation trial. During the 4 week covariate period all cows were fed the NS diet with 18 g/ton Rumensin® (NSR) followed by a 12 week treatment period with cows fed their assigned treatment diets of NSR, NS with 0 g/ton Rumensin®, RS with 0 g/ton Rumensin®, and RS with 18 g/ton Rumensin®. Diets were in a TMR mixed and fed once daily. Inclusion of Rumensin® at 18 g/ton DM improved lactation performance, specifically milk production efficiency, on both RS and NS diets (Figure 1). There were few significant interactions of starch and Rumensin®, thereby supporting the use of Rumensin® in both lactation diets tested in this study.

Broderick and Radloff (2004) partially replaced starch from high-moisture shelled corn (HMC) with sugar from either dried (Trial 1) or liquid (Trial 2) molasses. Dietary starch and total sugar concentrations (DM basis) ranged from 31.5% to 23.2% and 2.6% to 7.2%, respectively, in Trial 1, and from 31.4% to 26.1% and 2.6% to 10.0% in Trial 2. Cows averaged 128 and 85 DIM at trial initiation for Trials 1 and 2, respectively, and were on treatment for 8 wk. The estimated overall optimum for total dietary sugar, based on yields of fat and FCM in Trial 1 and yields of milk and protein in Trial 2, was 5.0% (DM basis); feeding diets with more than 6% total sugar with the added sugar from molasses appeared to depress milk production.

Broderick et al. (2008) partially replaced corn starch with sucrose. Dietary starch and total sugar concentrations (DM basis) ranged from 28.2% to 21.5% and 2.7% to 10.0%, respectively. Cows averaged 77 DIM at trial initiation, and were on treatment for 8 wk. Milk yield was unaffected by treatment, but milk fat yield was greatest for the diet containing 7.1% total sugar and 24.5% starch (DM basis). Alternatively, high-sugar ingredients include molasses, whey, whey permeate, liquid feed supplements, and sucrose. Evaluate prices of these ingredients (sugar) relative the price of corn (starch) to determine appropriate supplementation strategies.

DIGESTIBILITY OF CORN GRAIN STARCH

The impact of the digestibility of corn grain starch on lactation performance by dairy cows was reviewed by Firkins et al. (2001). Greater starch digestibility increased milk and protein yields. Research is limited, however, with regard to the impact of increasing starch digestibility in RS diets on lactation performance by dairy cows.

Three experiments evaluated the addition of exogenous amylase to RS diets (Gencoglu et al., 2010; Ferrareto et al., 2011b; Weiss et al., 2011). Gencoglu et al. (2010) reported that fat-corrected milk (FCM), SCM and energy-corrected milk (ECM) feed efficiencies (kg/kg DMI) were 12% to 13% greater for cows fed the RS diet with amylase than for cows fed the RS diet without added amylase. Amylase addition to RS diets tended (P < 0.09) to increase the actual milk feed efficiency by 6% in the Ferrareto et al. (2011b) trial, but was ineffective in the OARDC trial. Across these three trials with RS diets and in the trial of Klingerman et al. (2009) with NS diets, dietary addition of exogenous amylase more consistently increased NDF digestibility than starch digestibility. More research on exogenous amylase addition to both NS and RS diets is warranted.

Total tract digestibility of starch by dairy cows ranges between 70% and 100% (Firkins et al., 2001) with a host of factors that influence starch digestibility. These factors include particle size (fine ground vs. coarse rolled), grain processing (steam flaked vs. dry rolled), storage method (dry vs. HMC), moisture content and duration of silo fermentation for HMC, and type of corn endosperm (Firkins et al., 2001; Hoffman et al., 2011; Nocek and Tammenga, 1991).

Kernel vitreousness, the ratio of vitreous to floury endosperm, has been used to assess type of corn endosperm (Ngonyamo-Majee et al., 2008a, b). Increased kernel vitreousness was related to reduced ruminal in situ corn starch degradation (Correa et al., 2002; Ngonyamo-Majee et al., 2008b). Kernel vitreousness was lower and ruminal in situ starch degradation was greater for dry corn with floury or opaque endosperm compared to normal dent endosperm (Ngonyamo-Majee et al., 2008a, b). Taylor and Allen (2005) reported greater ruminal and total tract starch digestibilities in ruminally and duodenally cannulated lactating dairy cows for floury (3% vitreousness) than normal dent (67% vitreousness) endosperm dry corn. Highly vitreous corn types contain greater concentrations of prolamin proteins than floury or opaque corn types ( Larson and Hoffman, 2008). Starch granules in the corn endosperm are surrounded by hydrophobic prolamin proteins which are slowly degraded (McAllister et al., 1993). Lopes et al. (2009) conducted an experiment to evaluate the effect of type of corn endosperm on nutrient digestibility in lactating dairy cows using near-isogenic variants of a normal dent endosperm hybrid carrying floury-2 or opaque-2 alleles. The percentage vitreous endosperm was zero for floury and opaque endosperm corns and 64% for the vitreous corn. Prolamin protein content of floury and opaque endosperm corns was 30% of the content found in vitreous corn. Starch disappearance after 8-hr ruminal in situ incubation was 32%-units on average greater, respectively, for floury and opaque endosperm corns than vitreous corn. Total-tract starch digestibility was 6.3%-units, on average, greater for cows fed diets containing floury and opaque endosperm corns than vitreous corn.

Hoffman and Shaver (2009) developed a corn grain evaluation system (UWFGES) for dairy cows where total-tract starch digestibility, energy value, and relative grain quality index are predicted from equations that include starch content, mean particle size, prolamin protein...
content, and whether or not the corn is dry or HMC (> 22.5% moisture). This system, as originally proposed, however, does not account for effects of varying corn maturities, moisture contents or extents of silo fermentation. Hoffman et al. (2011) reported that ensiling HMC for 240 d reduced zein protein subunits that cross-link starch granules, and suggested that the starch-protein matrix was degraded by proteolytic activity over an extended ensiling period. This could explain reports of greater ruminal in situ starch degradability for HMC with greater moisture contents and duration of silo fermentation (Benton et al., 2005). The Larson and Hoffman (2008) turbidity assay determination of total zein protein content did not detect a reduction in zein protein subunits over the ensiling period for HMC as measured by high-performance liquid chromatography (HPLC; Hoffman et al., 2011). Ammonia content increased, however, as HPLC zein protein subunits in HMC decreased (Hoffman et al., 2011), and ammonia nitrogen has been suggested in combination with mean particle size for modeling the effects of corn maturity, moisture content and length of silage fermentation time on ruminal and total-tract starch digestibilities and rate of ruminal starch degradation for HMC at feed out (Hoffman et al., 2012). Effects of wide differences in corn grain vitreousness or prolamin, i.e. flinty or vitreous corn versus floury or opaque corn, on starch digestibility have been demonstrated (Correa et al., 2002; Ngonyamo-Majee et al., 2008a, b; Lopes et al., 2009; Taylor and Allen, 2005). However, incorporation of these corn endosperm properties into corn breeding or hybrid selection programs for dairy cattle feed has been, and continues to be, slow to evolve. Until the recent extended period of high corn prices there had not been much interest in increasing starch digestibility by exploiting corn’s genetic traits. Recent interest in feeding RS diets, however, has spawned a much greater interest in this area. Furthermore, the potential for reduced vitreousness or prolamin corn to reduce the cost and management of corn processing methods and quality control and HMC maturity, moisture content and duration of fermentation is of interest to some in the industry; more research is needed, however, to better evaluate these potential interactions.

While interest has increased along with on-going research, practical challenges to pursuing reduced vitreousness or prolamin corn remain. The relative importance of kernel vitreousness or prolamin appears to be as follows: dry corn > HMC > corn silage. The normal co-mingling of dry corn that occurs through grain elevators and feed industry channels makes it very difficult to alter these parameters at the feed manufacturer or farm level, and HMC and corn silage comprise more of a niche market for the seed corn industry. Incorporation of these parameters into routine corn hybrid selection programs requires NIRS calibrations, which are not available on an industry-wide basis at this point. The potential for pollen drift (Thomison, 2002) to compromise small replicated field plot hybrid evaluations for endosperm properties warrants more scrutiny. Nitrogen fertility can influence the prolamin content of corn grain (Masoero et al., 2011; Tsai et al., 1978), which could confound comparisons of field plot evaluations for this parameter across locations or companies. Important agronomic traits, such as yield and starch content, will also need to be evaluated relative to hybrid differences for vitreousness or prolamin. Much translational research is still needed for progress to be made in this area.

**CORN SILAGE FERMENTATION AND STARCH DIGESTIBILITY**

Newbold et al. (2006) reported that ruminal in situ starch and crude protein degradabilities increased for corn silage as the length of silage storage time increased. Increased corn silage in vitro starch digestibility with greater length of silage storage time was reported by Hallada et al. (2008) and Der Bedrosian et al. (2010). Young et al. (2011) reported that the addition of protease enzymes and greater length of the ensiling period increased ammonia nitrogen content and ruminal in vitro starch digestibility of corn silage. The DairyOne (Ithaca, NY) on-line data base (http://www.dairyone.com/) reveals that for over 12,000 corn silage samples analyzed from May-2000 through April-2011, ammonia nitrogen averaged 7.1% of total nitrogen with a normal range from 3.0 to 11.1%. In our analysis of a dataset provided by Dairyland Labs (Arcadia, WI) with over 1,900 corn silage samples, ammonia nitrogen averaged 5.7% of total nitrogen with a normal range from 2.7 to 10.7%. Additionally, in our analysis of a dataset provided by Cumberland Valley Analytical Services (Maugansville, MD) with about 44,000 corn silage samples from May-2007 through February-2012, ammonia nitrogen averaged 9.6% of total nitrogen with a normal range from 7.8 to 11.4%. Corn silage DM content explained almost none of the ammonia nitrogen variation in either dataset, which may not be too surprising since length of silage fermentation prior to on-farm sampling was unknown and could have ranged from less than a few weeks to over a year in storage. Research is needed to determine the effectiveness of ammonia nitrogen content in combination with some measure of particle size, possibly processing score (Ferreira and Mertens, 2005), for predicting corn silage starch digestibility parameters.

**REFERENCES**


Figure 1. Milk/DMI efficiency (lb/lb) of lactating dairy cows fed diets with and without Rumensin and different levels of starch. RSC = reduced starch diet without Rumensin; RSR = reduced starch diet with Rumensin; NSC = normal starch diet without Rumensin; NSR = normal starch diet with Rumensin. Starch x Rumensin, P = 0.08; SEM = 0.3.