

Optimizing Starch Concentrations in Dairy Rations

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Abstract

Currently, many nutritionists consider only the total nonfiber carbohydrate (**NFC**) fraction when formulating rations for lactating dairy cows. Increasingly, we need to measure the components that comprise NFC (starch, sugars, soluble fiber, and β -glucans) and formulate rations that optimize the concentration of each component in the diet. Starch is the major NFC fraction in dairy cattle diets, and some research has attempted to determine optimal dietary concentrations of either NFC or starch. However, an optimal amount of dietary starch will be a function of several factors, including the inherent degradability of the starch source, processing method, amount of soluble protein, neutral detergent fiber (**NDF**) content, feeding method, and environment. Commonly, dietary starch recommendations range between 23 to 30% of ration dry matter (**DM**) depending on forage content of the diet. The basis for this range in recommendations is a combination of some research but mostly anecdotal and experience-based observations in the field. The purpose of this paper is to explore some of the key factors that influence the optimal content of dietary starch, particularly considering diets high in fibrous byproducts.

Introduction

We cannot define an optimal dietary concentration of starch without considering other nutrient fractions in the diet. We need to define any

optimal starch concentration in relation to the concentration of other carbohydrate and protein fractions. Additionally, we must consider the ruminal degradability of the starch and other dietary carbohydrate fractions. In other words, we must optimize the entire carbohydrate profile, pool sizes and digestion rates, to optimally formulate a ration. Diets that contain appreciable quantities of fibrous byproduct feeds will be lower in starch content and higher in content of digestible NDF than typical diets for lactating dairy cows. As these diets become more commonly fed, particularly in the Midwestern US, we need to determine the optimal carbohydrate and protein fraction and rate profiles for these types of diets. Starch and fiber will be key components in determining the success of feeding diets high in nonforage sources of fiber, such as soybean hulls, corn gluten feed, distillers grains, beet pulp, and others.

We also need to consider the feeding environment and its potential impact on cow response to any particular amount of dietary starch. Management and housing factors that encourage abnormal feeding behaviors, such as slug feeding or sorting, will increase the risk of ruminal acidosis and associated problems for any concentration of dietary starch.

This paper will focus on the interactions among starch and other carbohydrate fractions, particularly NDF, although other factors are certainly important in determining cow response to

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starch, such as protein solubility (Hoover and Stokes, 1991).

Dietary Starch Improves Energy Content of the Diet

Starch represents a substantial fraction of dairy cattle diets, ranging from less than 20% (dry cow diets) to greater than 35% of lactating cow diets. Most of the dietary starch is supplied by cereal grains. Starch content of cereal grains ranges from 45% for oats to 72% for corn (DM basis). Forages vary in starch content from <15% of DM for alfalfa and perennial grass forages to as much as 35% for corn silage. Ruminal fermentation of starch is extremely variable from <50 to >90% and is a function of the rate of fermentation and retention time of feed particles in the rumen.

To increase energy intake by lactating dairy cattle, feeds high in starch are commonly substituted for fibrous forages and other feeds. Additionally, when diets higher in starchy grains, and consequently lower in NDF, are fed to lactating cows, the DM intake (**DMI**) usually increases (Allen, 2000).

The apparent digestibility of starch is approximately twice that of NDF when fed to dairy cows and should increase the energy content of the diet (Firkins et al., 2001). But, the actual increase in energy content of the diet may be less than predicted when starchy concentrates replace forages (Weiss and Shockey, 1991). Why is this response observed? When starch replaces dietary forage fiber, total tract digestion of NDF is often reduced (summarized well by Beckman and Weiss, 2005). A similar response has been observed when corn silage was rolled to increase ruminal starch digestibility and simultaneously ruminal NDF digestion was reduced (Fanning et al., 2002). In many feeding situations, increasing amount of dietary starch will reduce NDF content and thereby increase the probability of negative associative effects of starch on NDF digestion (Firkins et al., 2001).

Nonfiber Carbohydrate or Starch and Sugars?

Routine analysis of the NFC fractions is new for commercial testing laboratories. But, it is important to develop routine analyses for these fractions as they become more routinely used in ration formulation. Interestingly, a recent survey of nutritionists and consultants in the U.S. revealed that approximately 54% of them thought that an NFC or nonstructural carbohydrate (**NSC**) value was as good as individual starch or sugar analyses for ration formulation (L. Chase, Cornell University, 2005, personal communication). This response among consultants is likely to change as we learn more about starch and other NFC fraction utilization by cattle and more complex models are routinely used to formulate diets and predict animal response.

Even though the carbohydrate recommendations presented in Table 1 are based on a combination of research and field experience, use of these recommendations will allow us to better control the fermentation in the rumen of cattle at high levels of feed intake that is really one of our major goals as dairy nutritionists. Properly balancing the carbohydrate fractions in Table 1 should minimize the incidence of ruminal acidosis, maximize microbial yield, and minimize the need for relatively expensive supplemental sources of ruminally undegradable protein. We need to consider starch content and degradability, sugar content and whether there are differences among sugars in ruminal rate of fermentation, soluble fiber (pectin and β -glucans) content, rate of NDF digestion, NDF availability, and physically effective NDF (**peNDF**).

Starch is the only component of the NFC fraction that escapes from the rumen in substantial amounts. The amount that will escape ruminal fermentation depends on starch type, processing, feed intake level, the peNDF content of the diet, and pattern of daily meal consumption (highly influenced by feeding environment and management

routines). The impact of meal feeding patterns on starch utilization requires much more research. Starch comprises approximately 50 to 100% of the nonstructural carbohydrates in most feedstuffs. In addition to total starch concentration, the rate and extent of ruminal starch digestion also influences the amount of any particular starch source that may be fed safely in a diet (NRC, 2001). Rate of fermentation of starch varies considerably by type of grain and grain processing. Total tract starch digestion typically ranges from 85 to 99% (Firkins et al., 2001). Major factors that affect the measured starch digestion in dairy cattle include genetics of the grain, grain processing, the analytical method used to assay for starch, variable DMI, and the NDF content of the diet (Firkins et al., 2001).

Starch is variable in small intestinal and hindgut digestibility (Knowlton et al., 1999). For example, Knowlton et al. (1999) measured that as little as 55 and as much as 85% of corn starch appearing in the small intestine was digested; the lowest digestion was observed for dried corn, either ground or rolled, with high-moisture corn being highest. A probable explanation was the degree of gelatinization and the disruption of the protein matrix surrounding the starch. Steam flaked corn has greater fermentability in the rumen and greater digestion in the small intestine than steam rolled corn (Knowlton et al., 1999). Degree of processing is a major factor determining extent of digestion in both the rumen and hindgut.

Optimal Dietary NFC Content

Optimal concentration of NFC or NSC in diets for lactating dairy cows is not well defined as summarized in the most recent NRC publication (NRC, 2001). To avoid ruminal acidosis and other metabolic problems, the maximum concentration of NFC should be approximately 33 to 43% of ration DM (Nocek, 1997). Optimal NFC concentration in diets for high producing cows is a function of: 1) the effects of rapidly degradable starch on ruminal

NDF digestion, 2) amount of NFC that replaces NDF in the diet, 3) site of starch digestion, 4) DMI and physiological state of the animal, and 5) processing and storage methods that may alter rate and extent of NFC digestion (NRC, 2001). Obviously the same could be stated for starch since it is typically the largest fraction of the NFC pool.

Some research has attempted to define optimal ranges for dietary NFC. Most of these studies have found that diets containing <25 to 30% or >45% NFC resulted in reduced milk yield (Nocek and Russell, 1988; Hoover and Stokes, 1991; Batajoo and Shaver, 1994). The diets in these studies were based on combinations of alfalfa and corn silages and mostly traditional concentrate feeds. Recent research (for example Boddugari et al., 2001 and Ipharraguerre and Clark, 2003) with nonforage sources of fiber clearly demonstrates that dietary starch may be reduced to <25%, and NFC to <30%, with no negative impact on lactational performance. There was little difference in cow response for diets containing between 36 and 42% NFC (Batajoo and Shaver, 1994). Varga and Kononoff (1999) evaluated 16 studies and concluded that a 1 lb increase in NFC intake resulted in a 2.4 lb increase in milk yield.

Dietary NFC, Starch, and peNDF Contents

Haddad and Grant (2000) evaluated the effect of 30, 35, 40, or 45% NFC (obtained by adding corn starch to the diet) on the in vitro digestion kinetics of NDF from alfalfa or corn silages. Digestion was measured at low pH (5.8) or a higher pH (6.8) to mimic fermentation conditions representative of cows consuming a diet either deficient or adequate in peNDF. The optimal NFC to NDF ratio for maximal extent of ruminal NDF digestion differed between the two forages. For alfalfa fermented at pH 6.8, extent of NDF digestion was greatest between 30 and 40% NFC, but at pH 5.8, NDF digestion was greatest at 35% NFC. For corn silage fermented at either low or high pH,

NDF digestion was greatest at 30% NFC. A NFC to NDF ratio of 0.70-1.20 maximized NDF digestion for alfalfa only when pH was maintained at 6.8. This study demonstrated that the optimal dietary NFC content for maximum ruminal NDF digestion for a given forage is a function of fermentation pH that reflects the peNDF content of the diet.

Dietary Starch to Fiber Ratio

Recently, Beckman and Weiss (2005) published a paper that evaluated whether increasing dietary NDF:starch ratio influenced NDF digestibility when diets were formulated to have similar NDF digestibility. All diets contained 41.5% corn silage (DM basis), but the content of corn varied between 23.3 and 34.8% with NDF:starch ratios of 0.74, 0.95, and 1.27. A soybean hull:cottonseed hull mixture (54% soyhulls and 46% cottonseed hulls) which had the same NDF digestibility as the forage NDF was substituted for the corn grain in varying proportions to obtain the desired NDF:starch ratios. Starch content of these diets varied from 25.4 to 33.3%, and NDF varied between 24.7 and 32.2%.

Intake tended to increase as NDF:starch ratio increased and total tract DM and energy digestibilities decreased. However, NDF digestibility was not influenced by NDF:starch ratio. Greater DMI appeared to compensate for reduced digestible energy content such that energy intake was similar among the diets. This study demonstrated that NDF digestibility may be less sensitive to increases in the NDF:starch ratio under carefully controlled experimental conditions. Practically, there is almost always complete confounding of NDF and starch content, and the animal response is a composite response to all the carbohydrate fractions. Dietary formulation approaches that allow greater use of highly digestible NDF from byproduct feeds (replacing either forage or concentrate) represent a strategy for feeding either high or low starch diets and obtaining desirable lactational performance.

Nonforage Sources of Fiber and Dietary Starch Content

Recent research demonstrates that dietary NFC and starch contents may be reduced to low concentrations when high amounts of nonforage fiber sources are fed. Ipharraguerre et al. (2002) fed diets in which soybean hulls replaced ground corn from 0 to 40% of dietary DM. Corn was reduced from 40.3 to 1% of dietary DM. The dietary NSC (starch and sugars) ranged from 35.9 to only 15.6% of DM, while the NDF ranged between 26.6 and 45.4%. There were no differences among the diets, from high to low NSC, in either fat-corrected milk production or DMI.

Boddugari et al. (2001) evaluated diets in which a wet corn gluten feed product comprised up to 70% of the ration DM (replacing all of the corn grain and 50% of the forage). The NFC content ranged from 43.2 to 27.0% of DM across two studies. The efficiency of fat-corrected milk production (**FCM/DMI**) was similar for all diets, even when the content of NFC was much lower than commonly recommended. These studies were short-term (4-wk periods), and a subsequent trial evaluated response to a 40% wet corn gluten feed-based diet for the first 63 days in milk (Boddugari et al., 2001). The two diets contained either 43.6 or 35.1% NFC (0 versus 40% wet corn gluten feed product) and the efficiency of fat-corrected milk production was actually improved from 1.47 to 1.79 for cows fed the low NFC, low starch diet.

Biologically, significant differences exist among the commonly used byproduct feeds in their carbohydrate fractions. For example, Mills and Grant (2002) observed different lactational responses when either soybean hulls or wet corn gluten feed replaced corn grain at the same dietary NDF level. We need to keep this in mind as we incorporate various byproducts into rations. We will lower starch content, but depending on the byproduct, we will also have variable (and potentially

important) effects on other dietary carbohydrate fractions, such as sugars, soluble fiber, and organic acids. But, the two papers cited here clearly demonstrate the effectiveness of low starch, low NFC diets with two byproducts (soybean hulls and corn gluten feed) that vary dramatically in carbohydrate composition.

Interaction of Forage and Nonforage Fiber Sources

Fibrous particles have a high probability for escape from the rumen due to their small particle size and high specific gravity. They are rapidly fermented and so are less buoyant. Because most nonforage sources of fiber do not stimulate rumination as effectively as coarse forages, dietary forage must have adequate particle length for normal rumination when significant amounts of forage fiber are replaced with nonforage fiber. Additionally, forage of longer particle length forms a digesta mat that more effectively filters and entangles smaller particles (such as byproducts and fine forage particles), allowing greater time for fermentation in the rumen.

Nebraska researchers evaluated the effect of ruminal mat consistency on passage and digestion of wet corn gluten feed in lactating dairy cows (Allen and Grant, 2000). Diets were formulated to contain approximately 40% alfalfa, 24% wet corn gluten feed, plus a corn and soybean meal-based concentrate. One diet contained alfalfa silage and the other contained a 1:1 blend of alfalfa silage and coarsely chopped alfalfa hay of similar quality to increase particle size. Cows fed the diet with added hay and wet corn gluten feed had greater rumination activity and ruminal mat consistency, a 35% reduction in passage rate of corn gluten feed, 40% greater ruminal NDF digestion, and 6% more milk production. Earlier research has demonstrated the same positive effect with soybean hulls (Weidner and Grant, 1994). The bottom line is that adequate forage particle length and a well-formed ruminal

digesta mat will not only promote cow health but will slow passage of byproducts and allow more complete ruminal NDF digestion and greater productivity.

Summary

Prevailing recommendations for dietary starch range between 25 and 30% of DM. Many factors influence the optimal amount of starch, including intrinsic properties of the starch source, processing, animal factors (notably DMI level), other dietary fractions, and cow management. Altering the dietary content of starch necessitates changes in other carbohydrate fractions as well, and so we should focus on the ratio of starch to NDF (or starch to peNDF). When replacing forage NDF and (or) starchy concentrates with nonforage sources of fiber, we typically increase digestible NDF and reduce starch. Research has shown that byproduct-based diets can support excellent efficiency of milk production with much lower than commonly recommended amounts of starch and NFC.

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Table 1. Carbohydrate recommendations for lactating dairy cows.¹

Fraction	Amount
Total NDF, % of DM	28-32
PeNDF ² , % of NDF	20-24
Forage NDF, % of DM	18-23
Fermentable NDF, % of NDF	>35.0
NFC ³ , % of DM	30-43
Soluble fiber, % of DM	4-10
Starch, % of DM	23-30
Fermentable starch, % of starch	83-86
Sugars, % of DM	4-8
Sugar:soluble protein ratio	1.5:1
Fermentable total carbohydrates, % of DM	42-44
Total VFA ⁴ , % of DM	0-5

¹Adapted from Sniffen (2004).

²Physically effective neutral detergent fiber.

³Nonfiber carbohydrate.

⁴Volatile fatty acids.