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Considerations Associated with Corn Processing in Dairy Rations

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Summary

- Finer grinding or steam flaking of dry corn routinely increases starch digestibility in both the rumen and total tract and can provide more energy to support milk production so long as dry matter intake is not depressed.
- Although there are moderate trends for improvements in milk protein percentage associated with fine grinding or steam flaking, the risk of milk fat depression is more likely unless the amount of rumen-degraded starch is moderated.
- Research has documented likely responses and mechanisms for both decreasing efficiency of microbial protein synthesis in the rumen and decreasing dry matter intake associated with excessive supply of rumen-degraded starch.
- Fine grinding or steam flaking of corn should decrease variability associated with differing sources of corn grain (including vitreousness) as well as variability in estimation of digestion kinetics used in common ration evaluation software. Therefore, maximizing the rumen digestibility of starch while diluting the amount of corn grain using byproducts is a viable strategy when corn supplies are low and prices are high.

Introduction

The major energy sources for dairy cattle are from fat, protein, fiber, and non-structural carbohydrates (NSC). There is little opportunity to influence NE_L (net energy of lactation) intake by changing protein (although it obviously can influence dry matter intake, DMI, and milk protein production). Supplemental fats can increase NE_L intake, but fat density in a diet must be limited to prevent depressions in DMI, decreased marginal digestibility with high fat inclusion rates, or milk fat depression. Therefore, the major sources of NE_L are from fiber and starch. Starch digestibility in the total tract of the dairy cow can exceed 2x that of neutral detergent fiber (NDF), stimulating dairy nutritionists to maximize starch concentration for increased potential for milk production. On the other hand, when there is too much rumen degradation of starch relative to the concentration of physically effective NDF, either or both NDF digestibility and DMI can decrease. In concert with physically effective NDF to stimulate chewing and salivation, chemically effective NDF has a much slower rate of degradation in the rumen, diluting starch and helping to prevent excessive rate of volatile fatty acid production in the rumen. Therefore, current strategies might be to maximize the digestibility of corn starch while diluting the amount of that starch with increasing concentration of byproducts.

Forage type and particle size interacts with grain type and processing. In these scenarios, NDF digestibility can decrease, resulting in low feed conversion (milk:feed ratios), or milk fat percentage might decrease unexpectedly. Computer software is improving in its ability to predict negative associative effects, but these negative responses are still too often not diagnosed until profitability or cow health already have been impacted. Finally, with the increasing usage of corn for biofuels, improved efficiency of feed conversion is more likely to coincide with a greater push to use less corn and more byproducts. Consequently, we need to predict the amount of rumen-degraded starch (RDS) more reliably and use that information to make rations work more consistently with diverse forages, byproducts, and bunk management capabilities. My major emphases will be to discuss recent research 1) describing how processing of corn grain affects site of digestion and supply of microbial protein to the small intestine, and 2) how these processing effects interact with other dietary conditions to influence production of milk and milk components. My goal is that this information will help nutrition advisors diagnose differences among farms to help improve the amount or efficiency of milk production under their particular circumstances.

Improving Starch Digestibility to Enhance Milk Production

Numerous reviews have collated data among studies to obtain average values to account for variability among studies. These can provide potentially misleading information if the processing methods are not distributed in a balanced way across the various studies. Using a statistical procedure to reduce this potential bias, Firkins et al. (2001) summarized total tract digestibilities of nutrients (Table 1). We have made the calculation that the increase in organic matter digestibility through grain processing could provide enough NE_L to support 3-5 lb/day more milk so long as DMI does not decrease, and in general, the responses were in that range (Table 2). Most of these research studies used diets that had a fixed concentration of corn grain, and most of the forage was from alfalfa to ensure that nearly all of the starch in the diet was from the corn grain. Although DMI was not affected much, it is important to note that differences in milk production in Table 2 were scaled as if DMI was the same for all treatments. Therefore, the goal should be to either feed enough digestible starch to increase digestible energy and NE_L concentration while preventing a decrease in DMI that has been detected in many studies (see later discussion). Moreover, the data support a potential for a modest increase in milk protein percentage coinciding with a decrease in milk fat percentage with SF or high-moisture corn.

Firkins et al. (2001) also quantified differences in corn processing methods for ruminal digestibility and microbial N flow to the duodenum from studies comparing most of the corn processing methods (Table 1). Theoretically (and built into more sophisticated models), increasing starch digestibility in the rumen should support more microbial protein synthesis. In contrast, more aggressive processing of corn grain tended to increase starch digestibility at the expense of ruminal NDF digestibility. Also, the same conditions that are associated with depressions in NDF digestibility are associated with energy spilling reactions in microbes. Therefore, high-moisture corn had by far the greatest ruminal starch digestibility while having the lowest microbial N flow. This means that the efficiency of microbial protein synthesis must have declined. High-moisture corn contributes to chewing activity and probably has a lower ruminal passage rate, so rumen degraded protein (RDP) is likely to become limiting for microbial protein synthesis, further decreasing the efficiency of microbial protein synthesis. Oba and Allen (2003c) noted a similar marked decrease in the efficiency of microbial protein synthesis in dairy cattle fed high-moisture corn, and this will be discussed more later.

Intestinal Digestion of Corn Starch

In the past many researchers have tried to shift site of digestion of corn starch to the small intestine to improve its efficiency of conversion to NE_L. Theoretically, it is more efficient to digest starch and absorb glucose from the small intestine than to produce VFA in the rumen; only propionate and a minor amount of branched chain VFA can be net precursors for glucose synthesis in the liver (Arieli et al., 2001). However, those authors noted no benefit to intestinal versus ruminal availability of starch. Reynolds (2006) discussed liver metabolism within the context that increased glucose absorption from the small intestine doesn't necessarily increase peripheral glucose concentration or milk production. Oba and Allen (2003b) compared intestinal digestibility (% of duodenal flow) to the amount of starch reaching the duodenum and noted an increase until a plateau. In their study, though, dry shelled corn was ground to a mean particle size of about 0.9 mm. A coarser grind might physically decrease the susceptibility of duodenal grain particles to amylolytic enzymes, so other workers have noted that increasing duodenal flow (less rumen digestibility) was associated with a decreased digestibility in the intestine (% of duodenal flow) primarily by increasing the corn particle size. Practically, shifting starch digestion from the rumen to the intestines tends to be through less rigorous processing, which should decrease total tract digestibility (Table 1), which would probably negate the benefit in glucose metabolism in the intestine. Still, when expressed as a percentage of starch intake (not % of duodenal flow), most studies document large compensatory digestion in the small intestine when corn grain is rolled more coarsely (Callison et al., 2001; Rémond et al., 2004). With high-producing cows at a high DMI, grinding to a small particle size might allow a balance of starch digestion in the rumen to support microbial protein synthesis while washing out corn particles that are small enough to still have a high digestibility in the small intestine.

Some of the earlier studies that elevated the potential for starch digestibility in the small intestine were biased because they did not provide a long enough acclimation period to allow increased digestive capacity in the intestine when there was an increase in starch supply to the duodenum. Kentucky and Israeli workers (among others) have documented that increasing protein supply to the small intestine helps the animal to adapt its digestive capacity to handle larger amounts of starch reaching the duodenum (Abramson et al., 2005). Therefore, shifting too much starch to the small intestine could decrease the energy available for microbial protein synthesis and not really benefit the animal energetically. Further, calculations estimating efficiency of NE_L availability from digestibility of starch in the rumen versus the small intestine might be exacerbated by assuming a constant methane output relative to expected VFA production in the rumen (Harmon and McLeod, 2001). Although not clear, I think that increasing the rumen digestibility of starch provides consistency in ration balancing (there is less guessing of its actual digestibility) while being a more likely scenario to improve overall NE_L availability to support milk production. The real challenge is therefore to adapt systems to know how to balance rations for the amount of corn grain to optimize the amount of rumen-degraded starch (RDS).

Optimizing Rumen Degraded Starch

The amount of RDS consumed must be maintained to an adequate concentration to maximize the NE_L density while decreasing the risk of ruminal acidosis, decreased efficiency of microbial protein synthesis, and decreased DMI associated with excessive RDS intake. In contrast with other corn processing methods (grinding, flaking, and rolling) in Tables 1 and 2, there have been several more recent studies reinforcing our summary that feeding high-moisture shelled corn (HMC) versus dry ground corn has either decreased the efficiency of microbial protein synthesis or decreased DMI. Given that protein from soybean meal or other more expensive RUP sources is more costly than energy from grain and also that microbial protein has an excellent profile of amino acids (NRC, 2001), depressed efficiency of microbial protein synthesis really translates to depressed efficiency of conversion of dietary protein into milk protein (Firkins and Reynolds, 2005). In contrast with other Michigan State Studies in which HMC decreased efficiency of microbial protein synthesis compared with dry ground corn, increased substitution of beet pulp for HMC linearly decreased the amount of microbial protein flowing to the duodenum (Voelker and Allen, 2003b). Insufficient RDS clearly would therefore limit metabolizable protein for the cow (Voelker and Allen, 2003a). Had those researchers prepared diets lower in crude protein (18.0%), milk protein yield might have been decreased. Taken in total, both excessive and insufficient RDS should decrease the amount of microbial protein flowing to the duodenum. Finding the optimum amount of RDS for dairy rations will depend, in large part, on our ability to predict RDS in the face of so much variability associated with source of corn and processing conditions.

Predicting Rumen-Degraded Starch

There are several potential methods for predicting RDS. Taylor and Allen (2005b) suggested that in vitro starch digestibility should be used only as a general ranking of corn grains. All procedures are likely limited by whether or not grains are ground prior to whatever assay is used. With any in vitro procedure, there are considerable differences within labs (different reagents or rumen inocula), and this variation would be more severe among labs, particularly if using different in vitro procedures (Hall and Mertens, 2008). Firkins et al. (2001) discussed errors in starch measurement, although these issues are less concerning than 5-10 years ago through repeated efforts of Hall and coworkers (Hall, 2003). Still, readers should find out what procedure is being used by the lab, make sure it is documented using controlled research, and determine whether or not the assay includes free sugars. Oba and Allen (2003b) reported an interaction in the rate of starch digestibility in the rumen when two levels of corn grain (either dry ground or high moisture) were fed; this would mean that a rate being inputted into a model such as CPM might actually depend on its feeding level (which is not considered in ration systems). Also, users evaluating kinetics of grain degradation in situ should be aware that fine-grinding increases the instantaneously soluble fraction (Rémond et al., 2004), which is not necessarily instantaneously digestible without passage. Clearly, despite the increasing sophistication of ration evaluation software, there are still some limits regarding their inputs and the continuing need to retain the services of a good, discerning nutrition consultant.

Vitreousness of Corn Grain

In addition to increasing the surface area of starch granules, grinding also helps to break up protein complexes that inhibit starch degradation. In particular, corn kernels that have a greater contribution of vitreous endosperm have more zein protein, which is more resistant to proteolytic attack than other proteins found more in floury endosperm.

Taylor and Allen (2005b) selected two corn grains that were widely different in % vitreousness (Table 3). The site of digestion was shifted from the rumen to the intestines for the vitreous corn. Because the postruminal digestibility was about 8% lower when expressed relative to that entering the intestine, the total tract digestibility was about 5% lower. In a companion study (Taylor and Allen, 2005a), the vitreous corn tended ($P < 0.12$) to increase efficiency of microbial protein synthesis. Their correlation analysis shows that this efficiency was inversely correlated with starch digestion rate and positively related to ruminal pH and starch passage rate, which would be expected based on other reports from Dr. Allen's group. Even though these grains were selected to be diversely different, the differences were within the ranges of values seen for unselected corn grains comprising much of the literature (Firkins et al., 2001). Despite the selection criteria, the total tract digestibility of starch and total organic matter were only 4.6 and 3.3% units different, respectively. In this study, the mean particle sizes of the two corn grains were 1.4 and 1.6 mm.

In another publication with two different experiments (Rémond et al., 2004), a semiflint corn grain was ground to differing mean particle sizes (0.7, 1.8, and 3.7 mm). Increasing mean particle size of this corn grain decreased the apparent digestibility of starch in the rumen from 58.6 to 49.8 to 35.5%, but there was no compensation in the intestines because total tract digestibility still decreased from 91.4 to 86.0 to 69.5%. In contrast, when dent corn was ground or coarsely rolled (0.6 or 3.5 mm mean particle size) in their second experiment, there was a lower difference in rumen (69.8 and 53.5%) and total tract starch digestibility (97.3 and 89.2%), but results from such a large range in particle size were clearly much less than in the previous experiment with semiflint corn. Dry corn can be poorly digested in the total tract if it contains a lot of vitreous starch unless it is ground finely or steam-flaked. There simply aren’t enough studies for a “one size fits all” recommendation of mill size. However, grinding to less than 1.5 mm mean particle size might be adequate for floury corn grains because of potential compensatory starch digestion in the intestines, but vitreous grains probably should be ground to less than a mean of 1 mm to improve starch digestibility in the total tract.

There are laboratory measurements that can help improve the characterization of corn grain sources. Vitreousness can be visually appraised, and the assay often reported is from dissecting out the endosperm and determining the starch contribution as a % of the total. I recommend that if this procedure is done, then its main purpose would be to help nutrition advisors to know when to fine-grind corn. Gelatinization is being evaluated, but I have not seen conclusive published data for a wide range of conditions. However, gelatinization is clearly related to ruminal availability (Svihus et al., 2005). Pelleting has little apparent effect on starch digestibility compared with steam/expansion (Ljøkjel et al., 2003), and roasting has a minor impact on starch digestibility (Krizsan et al., 2007). Even extrusion only increased intestinal (not ruminal) digestibility of starch (Shabi et al., 1999). However, while roasting increased DMI, extrusion decreased DMI in those latter two reports. Without an apparent mechanism, these contrasting results support the need for on-farm monitoring of DMI to evaluate true efficacy. The question remaining to be answered, though, is how well is gelatinization related to total tract digestibility? If gelatinization results are moderate to high, more rigorous processing (e.g., grinding < 1 mm or steam flaking) benefits would be dampened, in part, by a shift in site of digestion from the intestines to the rumen with minor impact on nutrition and milk production; if gelatinization potential is low, then on-farm results should be more dramatic. Without better prediction characteristics, more rigorous processing (assumed at a modest cost) should help to limit the risks and problems associated with variation in feeding characteristics of corn. When assessing gelatinization, it is important to note that the sample needs to be taken from the grain actually consumed because starches can undergo retrogradation as processed grain dries and cools (Svihus et al., 2005), and such a process might leave the corn as bad or worse than before.

Lessons Learned from High Moisture Corn Studies

Although not as common as in the Midwest, HMC has been evaluated in several recent studies that should have some implications when comparing steam-flaked (SF) corn to dry ground corn in the Southwest. When HMC or dry ground corn were fed at 21 or 32% of the diet (Oba and Allen, 2003a; Oba and Allen, 2003c), the HMC decreased meal size. This HMC was only 63% DM, indicating a very highly available source. Interestingly, they noted an interaction in the average amount of starch consumed per meal. That is, with increasing amount of corn in the diet, increasing the RDS of that corn will decrease the average meal size for cows fed total mixed rations. Consequently, increasing the percentage of RDS in a diet above a threshold would be expected to decrease DMI proportionately. We did not measure the meal interval in our study with SF corn (Harvatine et al., 2002), but it depressed DMI by 1.1 kg/day compared with dry ground corn without depressing ruminal pH, and the trend was a greater depression of DMI when SF corn was fed in diets with greater substitution of whole cottonseed NDF for forage NDF. In our study, which used alfalfa haylage as the forage, cows fed the SF corn had greater microbial N flows to the duodenum despite the lower DMI. In contrast, in the Oba and Allen reports, which used corn silage, the mean ruminal pH of 6.12 was related to over 9 hours in which the pH was below 6.0. In this and other successive reports from their group, increasing volatility of pH was correlated with reduced efficiency of microbial protein synthesis by up to 20% compared with dry ground corn. Similarly, in corn silage-based diets, Taylor and Allen (2005a) also reported that efficiency of microbial protein synthesis was positively correlated with mean ruminal pH. Researchers from Allen's group have typically noted that microbial efficiency was positively related to ruminal starch passage rate. If undegraded corn particles might be an exit vehicle for bacteria, increasing outflow rate should enhance efficiency of their growth. In total, these results suggest that increasing RDS by processing corn more extensively is likely to either increase the volatility of pH and potentially decrease microbial protein flow or will depress DMI enough to prevent these issues. Of course, even if microbial N flow were not decreased, the decreasing DMI would obviously decrease the intake of RUP or other nutrients.

When HMC and dry cracked corn were processed to the same particle size, the retention time in the rumen was greater for cracked corn (Krause et al., 2002). Those authors described the effects of particle size and hydration on digestion and passage kinetics. Yet, passage rate did not decrease significantly when semiflint corn grain was processed to have increasing particle size (Rémond et al., 2004). In our review (Firkins et al., 2001), HMC seemed to stimulate chewing time, indicating that the larger corn kernels are residing in the rumen longer and being remasticated. Therefore, the greater potential from low pH resulting from increased ruminal availability of coarser rolled HMC typically fed would be compensated at least in part by increased salivary buffering. From extension of this information, feed ingredients that also stimulate rumination (e.g., cottonseed and to a lesser extent brewers grains, beet pulp, etc.) or that provide chemically effective NDF (e.g., soybean hulls, corn gluten feed, etc.) would also help prevent a decline in rumen pH or DMI by optimizing the amount of RDS when corn is steam-flaked or ground finely to increase its digestibility in the rumen.

Rumen-Degraded Starch and Dry Matter Intake

Regulation of DMI is multi-faceted and not fully understood (Allen, 2000). There are studies in which DMI is not depressed by more extensive grain processing. However, some responses (or lack thereof) can be explained by either DMI and milk production already being low (Rémond et al., 2004), or the forage was chopped very coarsely (Krause et al., 2003). Moreover, typical experimental designs often used alfalfa or grass as the main forage to concentrate the corn grain treatments as the main sources of starch in the total diet. When using corn silage, there already is a source of HMC, potentially increasing RDS above the threshold to depress DMI. In a factorial arrangement of treatments, increasing starch intake increased intake of digestible starch enough to enhance milk production only when the starch source was dry ground grain, not HMC (Oba and Allen, 2003a). In corn silage diets, increasing RDS by substituting dry ground corn for HMC decreased DMI (Krause and Combs, 2003). Beckman and Weiss (2005) reported that increasing dietary NDF percentage (diluting NSC and therefore RDS) tended to increase DMI. Because it is likely that a portion of cows will decrease DMI much more in response to high RDS than most other cows (Bradford and Allen, 2007), these responses might be hard to pick up in a group of cows on a farm. Moreover, starch infusion into the duodenum can depress DMI and depress milk fat (Reynolds, 2006), so excessive starch intake might not be just a ruminal effect. While not being fully predictable, these responses support a strong need to consider potential changes in DMI associated with changes in corn processing and to monitor DMI closely after.

Sugars and Rumen-Degraded Starch

Feeding smaller amounts of molasses or sugars could aggravate issues associated with excessive RDS or, conversely, might compensate for slower degradation rate in some corn grains. In the studies by Broderick and Radloff (2004), an optimum amount of about 6 and 5% total sugar was proposed for dried and liquid molasses experiments. Assuming 100% digestibility of the molasses product, I used a statistical procedure to estimate the total tract digestibility of organic matter of the HMC that was replaced by molasses products. This substitution procedure predicted the total tract OM digestibility of the HMC to be only about 65 and 89% in the trial with dried and wet molasses, respectively. Even if these values are not absolutely accurate, this exercise indicates that substitution of sugars for grain that is less digestible should provide more benefit than when the grain it replaces is already highly available in the total tract (and by correlation, in the rumen).

Firkins et al. (2008) added liquid feeds containing sugars either while increasing ruminal NSC digestibility or by diluting corn with soybean hulls to reduce or maintain ruminal NSC digestibility when all diets contained 30% corn silage and 15% chopped alfalfa hay. In the process, we estimated the rumen-degraded carbohydrate concentration using data from Table 1 and other sources. When rumen-degraded NSC (including starch and sugars) was increased by adding liquid feed in the 40% NFC diet, DMI was not increased (Table 4). However, when 3.25 or 6.5% liquid feed was added in 37% NFC diets formulated to have lower or the same rumen-degraded NSC, respectively, DMI increased significantly. Milk fat yield was greatest when cows were fed 3.25% liquid feed in the 37% NFC diets compared with control or when 3.25% liquid feed was added to 40% NFC diets. These results support earlier discussions that rations should moderate rumen-degraded NSC to maximize DMI and minimize the accumulation of fatty acid isomers that depress milk fat production. Also, particularly when corn grain is relatively more expensive, we can optimize the usage of that corn grain through extensive processing (e.g., steam flaking), thereby using by-products to dilute the NFC such that liquid feeds can provide a rapidly available carbohydrate and potentially stimulate palatability without providing excessive NSC availability. This study was done with individually fed cows, and the response might be even more beneficial in group-feeding situations through reduced particle sorting behavior.

Considerations for Dietary Feeding Practices Influencing Responses to Corn Processing

When diets included either corn silage or alfalfa hay as the sole forages, only corn silage decreased milk fat percentage when liquid feeds were added in combination with Rumensin (Oelker et al., 2006). These results were associated with a milk fatty acid profile that indicated that rumen biohydrogenation of fatty acids would increase the risk for milk fat depression on farms. Those diets also had 43% NFC (higher than that in Table 4). Krause and Combs (2003) reported that HMC decreased milk fat percentage compared with dry ground corn, apparently because of the higher ruminal NSC digestibility of the HMC. However, dry ground corn only depressed milk fat percentage when corn silage was added to the forage.

Metabolizable protein supplies are limited by methionine when alfalfa is the primary forage and by lysine when corn silage is the primary forage (Kleinschmit et al., 2007). To complement approaches to increase the supply of metabolizable amino acids, microbial protein supply should be maximized. Because increased frequency of feeding should reduce volatility associated with ruminal pH, ammonia concentration, and carbohydrate availability, Dhiman et al. (2002) compared dry ground versus SF corn fed once or four times daily (Table 5). Steam flaking depressed milk fat% regardless of feeding frequency (main effect of flaking), but feeding diets with SF corn more frequently combined to increase the percentage and yield of milk protein (a statistical interaction). Although the NRC (2001) indicates that SF corn should have more RUP, this wasn’t confirmed experimentally (Harvatine et al., 2002). Consequently, more frequent feeding to decrease the risk of slug-feeding and to help synchronize RDP availability might help to improve milk protein yield when diets contain SF corn.

Conclusions

There should be an optimum NSC availability in the rumen that is consistent with efficient rumen microbial metabolism and prevention of depressions in milk fat percentage or DMI. Ration balancing procedures based on ruminal kinetics will help to account for differences among corn processing methods. However, laboratory procedures that predict the rate and extent of ruminal starch degradation also are influenced by grinding size and other factors that might mask true differences when fed to cows. Although good for ranking, mean values from experiments also should be used as comparisons to reduce the risk of depressed DMI or milk fat percentage. Determination of vitreousness or perhaps gelatinization of dry corn grain should be considered as another ranking tool, particularly to help users know when to grind corn more finely or to predict greater responses from steam flaking. Using these considerations for coarse adjustment of rations, the amount of RDS can be fine-tuned with more slowly available byproducts or increased moderately with small amounts of sugars according to individual herd or group needs.

Literature Cited

Abramson, S. M., I. Bruckental, L. Lipshitz, U. Moallem, S. Zamwel, and A. Arieli. 2005. Starch digestion site: influence of ruminal and abomasal starch infusion on starch digestion and utilization in dairy cows. Anim. Sci. 80:201-207.

Allen, M. S. 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. J. Dairy Sci. 83:1598-1624.

Arieli, A., S. Abramson, S. J. Mabjeesh, S. Zamwell, and I. Brukental. 2001. Effect of site and source of energy supplementation on milk yield in dairy cows. J. Dairy Sci. 84:462-470.

Beckman, J. L., and W. P. Weiss. 2005. Nutrient digestibility of diets with different fiber to starch ratios when fed to lactating dairy cows. J. Dairy Sci. 88:1015-1023.

Bradford, B. J., and M. S. Allen. 2007. Depression in feed intake by a highly fermentable diet is related to plasma insulin concentration and insulin response to glucose infusion. J. Dairy Sci. 90:3838-3845.

Broderick, G. A., and W. J. Radloff. 2004. Effect of molasses supplementation on the production of lactating dairy cows fed diets based on alfalfa and corn silage. J. Dairy Sci. 87:2997-3009.

Callison, S. L., J. L. Firkins, M. L. Eastridge, and B. L. Hull. 2001. Site of nutrient digestion by dairy cows fed corn of different particle sizes or steam-rolled. J. Dairy Sci. 84:1458-1467.

Dhiman, T. R., M. S. Zaman, I. S. MacQueen, and R. L. Boman. 2002. Influence of corn processing and frequency of feeding on cow performance. J. Dairy Sci. 85:217-226.

Firkins, J. L., M. L. Eastridge, N. R. St-Pierre, and S. M. Noftsger. 2001. Effects of grain variability and processing on starch utilization by lactating dairy cattle. J. Anim. Sci. 79(E. Suppl.):E218-E238.

Firkins, J. L., B. S. Oldick, J. Pantoja, L. E. Gilligan, and L. Carver. 2008. Efficacy of liquid feeds varying in concentration and composition of fat, non-protein nitrogen, and non-fiber carbohydrates for lactating dairy cows. J. Dairy Sci. 91:(in press).

Firkins, J. L., and C. K. Reynolds. 2005. Whole animal nitrogen balance in cattle. Pages 167-185 in Nitrogen and Phosphorus Nutrition of Cattle and Environment. E. Pfeffer and A. Hristov, eds. CAB International, Cambridge, MA.

Hall, M. B. 2003. Challenges with nonfiber carbohydrate methods. J. Anim. Sci. 81:3226-3232.

Hall, M. B., and D. R. Mertens. 2008. In vitro fermentation vessel type and method alter fiber digestibility estimates. J. Dairy Sci. 91:301-307.

Harmon, D. L., and K. R. McLeod. 2001. Glucose uptake and regulation by intestinal tissues: Implications and whole-body energetics. J. Anim. Sci. 79(E. Suppl.):E59-E72.

Harvatine, D. I., J. L. Firkins, and M. L. Eastridge. 2002. Whole linted cottonseed as a forage substitute fed with ground or steam-flaked corn: Digestibility and performance. J. Dairy Sci. 85:1976-1987.

Kleinschmit, D. H., D. J. Schingoethe, A. R. Hippen, and K. F. Kalscheur. 2007. Dried distillers grains plus solubles with corn silage or alfalfa hay as the primary forage source in dairy cow diets. J. Dairy Sci. 90:5587-5599.

Krause, K. M., and D. K. Combs. 2003. Effects of forage particle size, forage source, and grain fermentability on performance and ruminal pH in midlactation cows. J. Dairy Sci. 86:1382-1397.

Krause, K. M., D. K. Combs, and K. A. Beauchemin. 2002. Effects of forage particle size and grain fermentability in midlactation cows. I. Milk production and diet digestibility. J. Dairy Sci. 85:1936-1946.

Krause, K. M., D. K. Combs, and K. A. Beauchemin. 2003. Effects of increasing levels of refined cornstarch in the diet of lactating dairy cows on performance and ruminal pH. J. Dairy Sci. 86:1341-1353.

Krizsan, S. J., G. A. Broderick, R. E. Muck, C. Promkot, S. Colombini, and Å. T. Randby. 2007. Effect of alfalfa silage storage structure and roasting corn on production and ruminal metabolism of lactating dairy cows. J. Dairy Sci. 90:4793-4804.

Ljøkjel, K., A. Skrede, and O. M. Harstad. 2003. Effects of pelleting and expanding of vegetable feeds on *in situ* protein and starch digestion in dairy cows. J. Anim. Feed Sci. 12:435-449.

National Research Council. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. ed. Natl. Acad. Sci., Washington, DC.

Oba, M., and M. S. Allen. 2003b. Effects of corn grain conservation method on ruminal digestion kinetics for lactating dairy cows at two dietary starch concentrations. J. Dairy Sci. 86:184-194.

Oba, M., and M. S. Allen. 2003a. Effects of corn grain conservation method on feeding behavior and productivity of lactating dairy cows at two dietary starch concentrations. J. Dairy Sci. 86:174-183.

Oba, M., and M. S. Allen. 2003c. Effects of diet fermentability on efficiency of microbial nitrogen production in lactating dairy cows. J. Dairy Sci. 86:195-207.

Oelker, E. R., C. Reveneau, and J. L. Firkins. 2006. Effects of molasses and monensin in alfalfa hay or corn silage diets on rumen fermentation, total digestibility, and milk production in Holstein cows. J. Dairy Sci. 89(Suppl. 1):127(Abstr.). (Abstr.)

Rémond, D., J. I. Cabrera-Estrada, M. Champion, B. Chauveau, R. Coudure, and C. Poncet. 2004. Effect of corn particle size on site and extent of starch digestion in lactating dairy cows. J. Dairy Sci. 87:1389-1399.

Reynolds, C. K. 2006. Production and metabolic effects of site of starch digestion in dairy cattle. Anim. Feed Sci. Technol. 130:78-94.

Shabi, Z., I. Bruckental, S. Zamwell, H. Tagari, and A. Arieli. 1999. Effects of extrusion of grain and feeding frequency on rumen fermentation, nutrient digestibility, and milk yield and composition in dairy cows. J. Dairy Sci. 82:1252-1260.

Svihus, B., A. K. Uhlen, and O. M. Harstad. 2005. Effect of starch granule structure, associated components and processing on nutritive value of cereal starch: A review. Anim. Feed Sci. Technol. 122:303-320.

Taylor, C. C., and M. S. Allen. 2005a. Corn grain endosperm type and brown midrib 3 corn silage: Ruminal fermentation and N partitioning in lactating cows. J. Dairy Sci. 88:1434-1442.

Taylor, C. C., and M. S. Allen. 2005b. Corn grain endosperm type and brown midrib 3 corn silage: Site of digestion and ruminal digestion kinetics in lactating cows. J. Dairy Sci. 88:1413-1424.

Voelker, J. A., and M. S. Allen. 2003b. Pelleted beet pulp substituted for high-moisture corn: 3. Effects on ruminal fermentation, pH, and microbial protein efficiency in lactating dairy cows. J. Dairy Sci. 86:3562-3570.

Voelker, J. A., and M. S. Allen. 2003a. Pelleted beet pulp substituted for high-moisture corn: 2. Effects of digestion and ruminal digestion kinetics in lactating dairy cows. J. Dairy Sci. 86:3553-3561.

Voelker, J. A., and M. S. Allen. 2003. Pelleted beet pulp substituted for high-moisture corn: 1. Effects on feed intake, chewing behavior, and milk production of lactating dairy cows. J. Dairy Sci. 86:3542-3552.

Table 1. Ruminal and total tract digestibilities of nutrients and duodenal flow of microbial N by lactating dairy cows fed different corn sources.[1]

	Total tract, %			Rumen, %			Duodenal microbial
Corn Source	Starch, Apparent	NDF	OM, Apparent	Starch, Apparent	NDF	OM, True	N, g/day
Dry, cracked or rolled	85.0	52.0	66.6	44.6	48.1	52.3	276
Dry, ground	90.7	49.0	67.8	52.3	44.9	48.6	257
Dry, ground finely	91.4	51.2	69.8				
Steam-rolled	88.8	49.8	67.2				
Steam-flaked	94.2	48.2	68.6	56.9	41.9	52.8	296
High-moisture, rolled	94.2	50.0	71.9	86.8	47.1	60.1	236
High-moisture, ground	98.8	50.4	73.9				

[1] Adjusted for effects of experiment and other significant variables (Firkins et al., 2001). All data are on an apparent basis (not accounting for endogenous or microbial contributions) except organic matter (OM) digestibility in the rumen. Note that 56.9% for steam-flaked corn is probably too low (should be around 65%), as explained in the paper.

Table 2. Lactation performance for Holstein cows fed different corn sources.[1]

Corn Source	DMI, kg/day	Milk, kg/day	Protein, %	Fat, %
Dry, cracked or rolled	22.5	30.9	3.09	3.59
Dry, ground	23.1	31.5	3.18	3.53
Dry, ground finely	21.9	32.4	3.02	3.49
Steam-rolled	22.1	31.9	3.10	3.49
Steam-flaked	22.8	32.5	3.10	3.36
High-moisture, rolled	22.7	32.5	3.17	3.54
High-moisture, ground	23.1	33.9	3.17	3.37

[1] Data are adjusted for effects of experiment and other significant variables (Firkins et al., 2001). To interpret these data for milk, the actual data were scaled to an average dry matter intake (DMI), so a lower DMI would decrease milk production to be less than the mean shown.

Table 3. Differences in digestibility between floury and vitreous corn grains in dairy cattle.[1]

	Floury	Vitreous
Vitreousness, %	3.0	67.2
Starch disappearance in vitro, %/hour	7.7	1.8
True starch digestibility in the rumen, % of intake	62.1	46.3
Apparent postruminal digestibility		
% of intake	39.3	56.8
% of duodenal flow	90.8	83.6
Apparent total tract digestibility, % of intake	96.3	91.7

[1] All means were $P<0.05$ except disappearance rate (statistics not done). Taylor and Allen (2005a).

Table 4. 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	*P*
DMI, kg/d	23.9^{b}	23.9^{b}	25.2^{ab}	25.9^{a}	24.5^{b}	0.08
Milk, kg/d	39.7	39.9	41.6	40.7	40.3	NS
Protein, %	2.93^{a}	2.82^{b}	2.85^{b}	2.85^{b}	2.83^{b}	0.01
Protein, kg/d	1.16	1.13	1.18	1.16	1.14	NS
MUN, mg/dL	12.3^{bc}	11.8^{c}	12.8^{b}	13.8^{a}	13.5^{a}	0.08
Fat, %	3.31	3.42	3.34	3.29	3.31	NS
Fat, kg/d	1.31^{b}	1.28^{b}	1.39^{a}	1.33^{b}	1.32^{b}	0.08
BW change, kg/d	0.51	0.28	0.33	0.58	0.46	0.13

[1] NFC = nonfiber carbohydrates, LF = liquid feed (Quality Liquid Feeds, Dodgeville, WI), and R = Rumensin® (Elanco Animal Health, Greenfield, IN). From left to right, using book values from Table 1 or from other sources, rumen-digestible NSC concentrations were formulated to be 16.9, 17.5, 16.0, 16.9, and 16.9% of dietary DM, respectively.

[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 ($P > 0.20$).

Table 5. Milk production by cows fed diets containing corn grain that was dry-rolled coarsely, dry-rolled finely, or steam-flaked (SF) and at either one (1x) or four (4x) times daily.

	Coarse 1x	Fine 1x	SF 1x	Fine 4x	SF 4x	Contrast[1]
DMI, kg/d	25.7	25.8	24.9	24.8	24.4	NS
Milk, kg/day	36.6	38.0	38.1	37.4	38.6	Flake (0.09)
Fat, %	3.34	3.17	2.89	3.21	3.02	Flake (0.01)
Fat, kg/day	1.26	1.18	1.09	1.19	1.14	Flake (0.01)
Protein, %	3.09	3.15	3.19	3.15	3.24	Inter (0.07)
Protein, kg/day	1.11	1.19	1.21	1.17	1.24	Inter (0.06)

[1] Non-significant ($P > 0.10$), main effect of flaking [(fine 1x + fine 4x) vs. (SF 1x + SF 4x)] or the interaction of processing and feeding frequency at the *P*-value shown.

Dhiman et al. (2002).

HIGH COW REPORT
September 2008

MILK

Arizona Owner	Barn#	Age	Milk	New Mexico Owner	Barn #	Age	Milk
*Stotz Dairy	18202	06-02	42,760	S.A.S. Dairy	8303	5-02	40,043
*Stotz Dairy	22818	03-04	41,280	S.A.S. Dairy	7111	6-06	39,091
*Goldman Dairy	9081	06-01	39,610	*Providence Dairy	6479	5-04	38,680
*Danzeisen Dairy 3	90757	04-11	38,620	*Providence Dairy	7632	4-04	38,230
*Goldman Dairy	7881	06-02	37,630	Arrowhead Dairy	2069	5-02	37,314
*Stotz Dairy	21938	04-00	37,530	*Opportunity Dairy	635	3-11	36,690
*Stotz Dairy	8440	05-09	37,200	Pareo Dairy	3674	6-01	35,752
*Stotz Dairy	20627	05-01	36,940	*Providence Dairy	6857	4-11	35,680
*Stotz Dairy	20465	05-03	36,650	S.A.S. Dairy	6896	6-09	35,610
*Stotz Dairy	20681	05-02	36,540	Pareo Dairy	5189	6-01	35,422

FAT

*Stotz Dairy	18202	06-02	1,648	*Providence Dairy	6479	5-04	1,510
*Stotz Dairy	20465	05-03	1,602	*Tee Vee Dairy	1021	7-06	1,505
*Stotz Dairy	20351	05-07	1,541	*Goff Dairy	15934	6-06	1,484
*Stotz Dairy	20487	05-04	1,517	S.A.S. Dairy	8303	5-02	1,428
*Shamrock Farms	15120	04-04	1,501	*Providence Dairy	2112	------	1,371
*Shamrock Farms	12205	05-03	1,472	Tee Vee Dairy	1474	6-06	1,345
*Stotz Dairy	22818	03-04	1,472	Cross Country Dairy	605	5-06	1,341
*D & I Holstein	1682	05-02	1,463	Pareo Dairy	8	7-05	1,335
*D & I Holstein	3114	05-08	1,462	Pareo Dairy	5189	6-01	1,331
*Shamrock Farms	11300	05-05	1,447	*Opportunity Dairy	635	3-11	1,325

PROTEIN

*Stotz Dairy	18202	06-02	1,327	*Providence Dairy	7632	4-04	1,167
*Stotz Dairy	22818	03-04	1,116	S.A.S. Dairy	8303	5-02	1,164
*Danzeisen Dairy 3	90757	04-11	1,099	*Goff Dairy	15934	6-06	1,141
*Goldman Dairy	7881	06-02	1,098	*Providence Dairy	6479	5-04	1,109
*Goldman Dairy	9081	06-01	1,096	*Goff Dairy	24537	3-04	1,098
*Stotz Dairy	20351	05-07	1,084	Red Roof Dairy	559	6-02	1,091
*Stotz Dairy	20465	05-03	1,081	S.A.S. Dairy	8303	5-02	1,090
*Stotz Dairy	20326	05-06	1,064	*Providence Dairy	3861	----	1,086
*Stotz Dairy	20726	05-01	1,061	S.A.S. Dairy	7111	6-06	1,084
*Stotz Dairy	16752	07-05	1,059	Cross Country Dairy	1191	5-06	1,074

*all or part of lactation is 3X or 4X milking

ARIZONA - TOP 50% FOR F.C.M.[b]
September 2008

OWNERS NAME	Number of Cows	MILK	FAT	3.5 FCM	DO
Stotz Dairy West	2,225	28,711	1,044	29,345	201
Danzeisen Dairy, Inc.	1,775	25,884	932	26,307	185
Stotz Dairy East	1,221	25,127	918	25,752	192
Goldman Dairy	2,420	24,830	841	24,374	165
Zimmerman Dairy	1,217	23,659	846	23,950	156
Arizona Dairy Company	5,743	22,862	807	23,636	197
Butler Dairy	622	23,733	820	23,554	
Shamrock Farms	8,259	24,040	801	23,284	159
Mike Pylman	7,121	23,290	806	23,141	220
Withrow Dairy	5,163	22,790	796	22,763	156

NEW MEXICO - TOP 50% FOR F.C.M.[b]
September 2008

OWNERS NAME	Number of Cows	MILK	FAT	3.5 FCM	CI
*Arrowhead	3,089	21,740			15.90
Breedyk	2,739	21,675	711	20,902	14.33
*Butterfield	2,199	25,308	873	25,100	13.56
Caballo	3,750	21,487	743	21,339	13.50
*Clover Knolls	3,433	24,495	823	23,937	12.60
Cross Country	3,408	22,257	801	22,613	13.23
*Desperado	2,356	15,902	649	17,400	13.01
*Do-Rene	2,352	24,368	806	23,607	11.50
Dutch Valley Farms	3,754	14,970	679	17,484	13.12
Flecha	2,587	21,368	764	21,629	13.26
*Goff	5,936	23,162	761	22,356	13.65
*Goff 2	3,243	16,103	706	18,411	13.73
*Hide Away	3,969	22,194	762	21,953	13.00
*High Plains	1,177	18,618	684	19,142	15.50
McCatharn	1,128	24,393	849	24,315	13.30
*Mid Frisian	1,541	21,468	759	21,591	13.91

* all or part of lactation is 3X or 4X milking

[b] average milk and fat figure may be different from monthly herd summary; figures used are last day/month

ARIZONA AND NEW MEXICO HERD IMPROVEMENT SUMMARY FOR OFFICIAL HERDS TESTED SEPTEMBER 2008

		ARIZONA	**NEW MEXICO**
1.	Number of Herds	30	27
2.	Total Cows in Herd	68,755	67,541
3.	Average Herd Size	2,292	2502
4.	Percent in Milk	86	87
5.	Average Days in Milk	218	203
6.	Average Milk – All Cows Per Day	51.2	63
7.	Average Percent Fat – All Cows	3.7	3.55
8.	Total Cows in Milk	57,985	58,761
9.	Average Daily Milk for Milking Cows	60.7	69.10
10.	Average Days in Milk 1st Breeding	88	76
11.	Average Days Open	175	145
12.	Average Calving Interval	14.5	14.10
13.	Percent Somatic Cell – Low	83	81
14.	Percent Somatic Cell – Medium	11	15
15.	Percent Somatic Cell – High	6	4
16.	Average Previous Days Dry	64	63
17.	Percent Cows Leaving Herd	32	34
	Milk	22,192	19,192
	Percent butterfat	3.60	3.60
	Percent protein	2.97	3.10
	Pounds butterfat	796	835
	Pounds protein	656	689

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