IMPACT OF GRAIN PROCESSING AND QUALITY ON HOLSTEIN STEER PERFORMANCE

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Introduction and Background

The topic of grain processing for feeding ruminants has been reviewed extensively (Nocek and Tamminga, 1991; Huntington, 1997; Theurer et al., 1999; Rowe et al., 1999; Harmon and McLeod, 2001, 2005; Firkins et al., 2001; Harmon et al., 2004; Owens and Zinn, 2005). This review outlines results from trials with feedlot cattle irrespective of breed, with emphasis on digestibility of starch, the primary component of cereal grains and the major source of digestible energy in most feedlot diets. Through generations of selection for milk yield, Holstein cattle differ from beef breeds. Compared with beef steers, Holstein steers have 1) larger frame size and less subcutaneous fat at a specific weight, 2) greater feed intake, 3) greater water intake that is associated with either 4) larger ruminal volume per unit weight or 5) faster outflow of ruminal contents. Very few direct breed comparisons have been published. Consequently, discussion will deal with general aspects of grain processing irrespective of breed. All digestion values cited represent the disappearance of a given nutrient within a specific location in the digestive tract without adjustment for microbial constituents.

Why is grain processed? Although processing grain simplifies mixing grain with other diet ingredients and reduces separation of diet components both during feed preparation and in the feed bunk, the primary reason for processing grain more vitreous grains (corn, sorghum) for livestock is to enhance nutritional value. Feeding value of a cereal grain is a function of several factors: its nutrient content, various physical and chemical characteristics that affect digestibility, acceptability (palatability) as it alters feed intake, and associative interactions with the digestive process. Although very extensive processing (extrusion, flaking to extensively gelatinize starch) can maximize digestibility, typical grain processing methods used for cattle are selected to economically enhance digestibility and acceptability without detrimentally affecting ruminal pH and causing digestive dysfunction. Milling with a roller mill or grinder simply to reduce particle size yields dry rolled or dry ground grain is the simplest approach to enhance digestibility.

Addition of water with or without a wetting agent prior to rolling or grinding helps reduce the amount of flour generated, dustiness of the product, and separation of fines that may cause metabolic problems or reduced feed intake. Given the proper storage structures and covering, grain can be fermented anaerobically at a high moisture level using moisture present in the grain before the grain has matured in the field to yield high moisture grain or by adding water to dry rolled or ground grain to form reconstituted grain. Heat can be applied before rolling, yielding steam rolled or "flaked" grain.

Compared with flaked grain, steam rolled grain has a shorter steaming time, crushed flakes are thicker, and starch is less damaged (gelatinized). More extensive processing methods (pelleting, extrusion) that are used to make poultry, pet, and horse feeds are not used widely for processing grains for ruminants. Responses to the 3 common processing methods (rolled or ground grain; high moisture grain; steam flaked grain) in site and extent of digestion can differ with the grain being processed as well as processing conditions (final particle size; fermentation moisture; fermentation time; test weight or thickness of flakes; degree of starch damage or “gelatinization”). In addition, the hybrid or variety of the grain and agronomic conditions can influence response to processing. Finally, chewing and rumination as well as feeding management systems can alter site and extent of digestion and passage rate through the digestive tract; these vary with animal age and background, diet composition, feeding frequency, and dietary forage NDF level.

The goal of this paper is to 1) update estimates of site and extent of digestion by cattle fed different cereal grains subjected to various commercial processing methods, 2) examine additional factors that can the impact of diet composition and intake on site and extent of digestion, 3) discuss methods to evaluate adequacy of processing, and 4) outline specific anecdotes about feedlot Holstein steers as they relate to digestion and nutrient utilization. Due to page limits, readers are directed elsewhere (Owens and Zinn, 2005) for discussion of 1) specific grain components that limit digestibility of grain, 2) the energetics of fermentation in the rumen versus digestion in the small intestine, 3) variability among hybrids processed by various methods, 4) the impact of grain processing on diet formulation (e.g., NDF level) and 5) selecting a hybrid for maximum economic return for various individuals in the production chain (based on grain yield per acre versus beef production per ton versus beef production per acre).

Site and Extent of Starch Digestion by Cattle

Results from 48 published trials and two unpublished trials from 1990 to 2004 that tabulated site of starch digestion for feedlot cattle (steers and heifers) were summarized from cited sources. Trials included site of digestion measurements with 180 different diets; each measurement was the average of several cattle (mean of 4.7) fed each diet. Primary measurements of concern were: 1) percentage of dietary starch apparently digested in the rumen, 2) percentage of starch flowing out of the rumen that was digested in the intestines, and 3) total tract starch digestion. These components were analyzed statistically to generate means weighted by the number of cattle measurements in each mean. In addition, digestibility at various sites was calculated by regressing starch digestion or disappearance against starch intake or starch supply. Effects of diet composition (N, starch, NDF) and other management and ruminal factors (intake as a fraction of body weight; ruminal dilution rate for concentrate) on site and extent of starch digestion also were examined.

Least squares means for each grain and processing method are presented in Table 1. As noted in previous reviews, site and extent of digestion differed with grain source;

ruminal and total tract disappearance of starch were considerably greater for rolled barley and wheat than for rolled corn and sorghum grain. Furthermore, the starch

Table 1. Trial Means for Site and extent of starch digestion by feedlot cattle fed diets containing several grains processed in various ways

Processing method	Dry rolled	High moisture	Steam flaked	Whole
Barley				
Ruminal disappearance, % of dietary starch	86.2 [b]		89.2 [a]	
Intestinal disappearance, % of flow	81.6 [b]		90.5 [a]	
Total tract disappearance, % of dietary starch	97.1 [a]		99.1 [a]	
Fraction disappearing in rumen, % of digested	88.5 [a]		90.2 [a]	
Corn				
Ruminal disappearance, % of dietary starch	60.6 [d]	91.0 [a]	84.2 [b]	74.3 [c]
Postruminal disappearance, % of flow	68.4 [d]	90.4 [b]	94.1 [a]	31.4 [e]
Small intestinal disappearance, % of flow	49.8 [b]		88.4 [a]	
Total tract disappearance, % of dietary starch	89.3 [c]	99.2 [a]	99.1 [a]	83.6 [d]
Fraction disappearing in rumen, % of digested	68.3 [c]	91.8 [a]	84.9 [b]	89.5 [b]
Sorghum				
Ruminal disappearance, % of dietary starch	66.8 [b]		84.9 [a]	
Postruminal disappearance, % of flow	89.0 [a]		92.1 [a]	
Small intestinal disappearance, % of flow	85.0 [b]		81.3 [a]	
Total tract disappearance, % of dietary starch	96.5 [b]		98.8 [a]	
Fraction disappearing in rumen, % of digested	69.4 [b]		85.9 [a]	
Wheat				
Ruminal disappearance, % of dietary starch	86.0 [a]		91.6 [a]	
Postruminal disappearance, % of flow	84.6 [a]		85.2 [a]	
Total tract disappearance, % of dietary starch	97.9 [a]		98.8 [a]	
Fraction disappearing in rumen, % digested	87.8 [a]		92.8 [a]	

[abcde]Means in the same row sharing a superscript are not different ($P < .05$)

digestion response to processing was considerably less for barley and wheat than for corn and sorghum grains. As compared with dry rolled grain, steam flaking of corn or sorghum grain for steers increased ruminal and total tract starch disappearance and shifted the site of digestion toward the rumen. More complete information about various processing methods is available for corn than for other cereal grains. Compared to starch from corn processed by other methods, ruminal starch digestion was quite extensively for high moisture corn, primarily due to greater ruminal digestion. As a fraction of total tract starch digestion, the proportion disappearing postruminally from processed grains (flaked, high moisture) was much lower for dry rolled grains than for processed grains. To further assess digestion responses to processing and examine the impact of starch intake on site of digestion, total tract digestion was regressed against starch intake for corn grain, the grain for which the most information is available, as an example of the impact of processing on site of digestion. These estimates are presented in Table 2.

Table 2. Impact on processing of corn grain on site and extent of digestion estimated by regressing digested starch against dietary supply or intestinal flow.

Processing method	Dry rolled	High moisture	Steam flaked	Whole
Ruminal disappearance, % dietary starch	70	91	85	75
Intestinal digestion, % of starch supply	72	89	94	42
Total tract disappearance, % dietary starch	91	99	99	85

Graphic presentations outlined previously (Owens and Zinn, 2005) show that lines differed due to grain processing indicating that corn processed by these 3 methods differed in digestibility. In addition, ruminal, intestinal, and total tract digestion did not decline as starch intake was increased suggesting that no limits or ceiling for starch digestion was being reached at higher starch intake levels. Although starch digestion was not depressed by higher intakes, processing did alter digestion of other diet components including fiber (NDF) both in the rumen and total tract. Fiber digestion is lower when corn is fed as flaked grain than as rolled grain, so site and extent of fiber digestion can be altered by different grain processing methods. However, no decrease in extent of starch in the total digestive tract was reached at these starch intakes by feedlot cattle.

Extent of dietary starch disappearing in the rumen was considerably greater with high moisture and steam flaked than dry rolled, and whole corn (91 and 85 versus 70 and 75%). The high extent of starch disappearance from high moisture and steam flaked corn matches with the high total tract digestibility of grain processed by these methods. However, with an increased ruminal digestion comes an increased likelihood of rapid acid production that can cause ruminal acidosis. Ruminal digestion of starch from whole corn surprisingly was slightly greater than for rolled grain. This may reflect longer ruminal retention time and greater rumination of whole corn than of rolled corn. Indeed, the whole corn diets in these trials averaged under 10% roughage whereas with diets with rolled corn averaged more than 15% roughage (corn silage plus alfalfa). Lower dietary roughage levels can prolong particle retention in the rumen and lead to more extensive ruminal fermentation.

Similar to the increased ruminal digestion with flaked and high moisture corn, intestinal starch disappearance as a fraction of the starch entering the small intestine was greater for high moisture and steam flaked than dry rolled, and whole corn grain (89 and 94% versus 72 and 42%). This difference probably is a function of limited accessibility of starch to digestive enzymes due to larger particle size of rolled and whole corn. Abomasal flow of starch as high as 2000 g daily caused no decrease in the fraction of starch that was digested in the intestines. No quadratic effects indicating a limit or ceiling to intestinal digestion of starch was apparent. However, because whole and dry rolled corn supplied more starch to the intestines (1106 and 1039 g/day) than flaked or high moisture corn (420 and 387 g/day) and also were less extensively digested in the intestines, if one extrapolated intestinal digestion across all processing methods, as would be necessary when data were more limited, one would conclude that intestinal digestion of starch DECREASES as starch flow to the intestines increases. In contrast, when digestibility was considered WITHIN a processing method, no indication of decrease of intestinal digestibility associated with an increased starch supply to the intestines was evident. Consequently, the capacity of the intestines to digest starch certainly was not overwhelmed by a large supply of starch in this summary with steers or in previous studies with lactating cows (Owens and Zinn, 2005) where intestinal starch supply was more than twice the supply observed with steers.

Diet composition, intake level, and ruminal passage rate can alter the site and extent of digestion. To examine effects across corn processing methods, starch digestibility responses were examined as they might relate to 1) diet composition (percentage of N, starch, NDF), 2) feed intake (dry matter intake as a fraction of body weight) and 3) concentrate dilution rate (calculated from intake and diet NDF as proposed by Seo et al., 2004). Results are presented in Table 3.

First, with flaked barley and rolled wheat, an increase in feed intake and an increased ruminal outflow (kp) rate tended to depress total tract starch digestion due to reduced intestinal disappearance. This suggests that very high intakes of diets containing wheat or barley might reduce intestinal digestion of starch in contrast with corn-based diets discussed above. Responses to diet modification were most frequent with dry rolled corn, probably because many trials had been conducted with rolled corn. For rolled corn, increasing protein content of the diet by 1% increased total tract starch digestibility by nearly 6%, largely due to increased intestinal digestion of starch. Increasing ruminal outflow rate (kp) increased total tract starch digestion through increasing intestinal digestion while decreasing extent of ruminal digestion. More dietary starch slightly decreased total tract starch digestibility by enhancing ruminal starch digestion and slightly depressing intestinal starch digestion.

The only factors that altered site or extent of digestion of starch from flaked grain were an increase in ruminal starch digestion from higher levels of dietary starch and a decrease in intestinal digestion with more dietary fiber. In contrast, with steam flaked sorghum grain, increasing dietary NDF increased intestinal starch digestion. While clear explanations for all these changes are not available, results could be interpreted to suggest that increasing the supply of starch from corn may increase the ruminal population of microbes that digest starch leading to greater starch digestion in the rumen. The increase in total tract digestion of starch from dry rolled corn grain with higher dietary protein levels occurred in the intestines, not the rumen.

Table 3. Influence of diet composition, intake, and passage rate on site and extent of starch digestion (change in percent of supplied starch digested per unit change).

Grain Process	Barley Flaked	Corn Dry rolled	Corn Flaked	Sorghum Flaked	Wheat Dry rolled
Total tract digestion					
Diet NDF, % (1%)	-	-	-	0.1	-0.2
Diet CP, %(1%)	-	5.8	-	-	-
Kp (1%/hour)	-2.5	2.5	-	-	-7.1
DMI (1% of BW/d)	-2.3	-	-	-	-15.0
Diet starch,% (1%)	-	-0.1	-	-	-
Ruminal digestion					
Diet NDF, % (1%)	-	-	-	-	-
Diet CP, % (1%)	-	-	-	-	-
Kp (1%/hour)	-	-7.8	-	-	-
DMI (1% of BW/d)	-	-	-	-	-
Diet starch, % (1%)	-	0.7	0.2	-	-
Intestinal digestion					
Diet NDF, % (1%)	-	1.3	-0.7	0.5	-1.6
Diet CP, % (1%)	-	19.3	-	-	-
Kp (1%/hour)	-29.0	11.3	-	-	-57.0
DMI (1% of BW/d)	-27.0	-	-	-	-121.0
Diet starch, % (1%)	-	-0.8	-	-	-2.0

Kentucky workers (Richards et al., 2002) working with rolled corn diets previously indicated that a higher level of dietary protein enhanced intestinal starch digestion by increasing amylase supply or stability. Alternatively, higher protein levels could increase the supply of ammonia for neutralizing acids produced in the large intestine; this could reduce the acid load that may inhibit amylose fermentation by bacteria in the large intestine. With dry rolled corn, as would be expected with all diets, increasing rate of passage of particles through the rumen shifted site of starch digestion from the rumen to the small intestine and surprisingly increased intestinal digestion of supplied starch.

This might be attributed to increased numbers of amylose-digesting bacteria in the large intestinal. In contrast to responses with rolled grain, with flaked barley and rolled wheat, intestinal capacity to digest starch failed to adapt to an increased starch supply; instead intestinal starch digestion was reduced even though intestinal starch supply was minimal with such diets (Table 1). If certain characteristics of the starch granules from wheat or barley are responsible for this reduction, efforts to increase ruminal escape of starch from these grains currently underway may not prove useful to enhance energy value even such a change could reduced the incidence of ruminal acidosis.

Effects of grain processing on available energy supply

Although the major response to processing grains is to increase digestibility of energy from starch, processing also increases digestibility of most other nutrients from grain as well (Zinn et al., 2002). These increases in the extent of energy digested result in an increase the total digestible nutrient (TDN) content from which metabolizable (ME; Table 3) and net energy values are calculated. To calculate ME by standard procedures, a constant fraction (28%) is subtracted as an estimate of energy lost in urine and as methane (NRC, 1996). Alternatively, one can predict ME values for a grain by measuring carcass energy retention or estimating energy retention from rate of gain and feed intake. Such values for individual grains and processing methods and are noted under the second column under each heading in Table 3.

Why did processed grains have greater ME when estimated from animal performance than from digestibility alone? This difference can be ascribed either to 1) reduced loss of energy as methane from more extensively processed grain value or 2) an enhanced value for end-products digested from grain following processing associated with an altered site of digestion, e.g., a reduction in inefficient fermentation in the large intestine. One can estimate methane loss from ratios of fermentation acids present in the rumen. Indeed, in one recent trial (R. A. Zinn, personal communication), corn grain from four hybrids was either rolled or flaked prior to feeding as 73% of diet dry matter to steers. Greater total tract starch digestion of the diet containing flaked grain increased supply of digested energy by 5.8%; increased digestibility of other grain components increased digested energy supply by an additional 4.2% for a total of 10%. But flaked grain resulted in a large increase in the propionate to acetate ratio in the rumen indicating that methane loss had been reduced substantially, by an additional 3.4%.

Added to the increase in digestibility, an energy savings of 13.4% from processing corn that comprised 73% of the diet means that metabolizable energy value of the grain alone was increased by 19% (13.4%/.73) by flaking. This value matches the increase in ME value based on steer performance (16% based on Table 3; 18% from Zinn et al., 2004) indicating that NRC estimates that subtract a constant fraction of digested energy to account for methane and urinary energy loss fails to adequately value extensive processing methods. This illustrates the quantitative importance of methane as a source of energy loss and its relevance in determining energy balance. Consequently, for formulating diets, energy values calculated from performance seem preferable to those calculated from digestibility alone. However, additional factors can reduce methane loss (feeding ionophores, supplemental fat, and high feed intakes or low roughage levels). Energetic benefits from these factors should prove greater when methane production is high (with less processed grains) than when methane production is already reduced (with flaked or high moisture grains).

Table 3. Estimated energy content of cereal grains processed by various methods based on digestibility measurements (NRC, 1996) or from rate of gain and feed intake of finishing cattle (Owens, 1997)

ME content (Mcals/kg DM) of grains								
	Barley		Corn		Milo		Wheat	
	NRC	Owens	NRC	Owens	NRC	Owens	NRC	Owens
Item	1996	1997	1996	1997	1996	1997	1996	1997
Whole	3.04	2.89	3.18	3.50?	2.75	-	-	-
Dry rolled	-	3.57	3.25	3.21	2.96	2.90	3.18	3.29
Steam Flaked	-	3.54	3.36	3.71	3.18	3.51	-	3.74
High Moisture	-	-	3.36	3.43	-	3.19	-	-

Optimizing Processing Conditions

Dry rolled and whole grains. As noted in classic studies from Beltsville (Moe and Tyrrell, 1976), corn grain must be ground finely for maximum total tract digestion. Certainly, particles that are large and resist water uptake will resist both microbial attack in the rumen and enzyme attack in the intestines. Intestinal starch disappearance of rolled corn grain at 64% of starch entering the small intestine and over 80% for starch from other rolled grains (Table 1) seems surprisingly high. However, about half of the starch from rolled corn disappearing in the intestines was fermented in the large intestine rather than being digested in the small intestine (Table 1). So fine grinding enhances extent of starch digestion, partly due to enhanced starch disappearance in the rumen and partly from increased fermentation of starch in the large intestine. Hutjens (1998) described the use of sieve boxes to appraise the particle size of ground grain; for dry rolled corn, his recommended particle distribution among boxes would be achieved at a geometric mean diameter (GMD) of 1150 to 1250 microns. By comparison, corn for pigs usually is ground to a GMD between 400 and 600 microns for maximum digestion. Because fine starch particles are fermented very rapidly in the rumen and thereby may cause acidosis, fine grinding typically is avoided for starch-rich feeds fed to ruminants. However, if sufficient roughage is present in the diet to prevent acidosis, as with typical dairy diets for cattle adapted to and frequently fed a totally mixed ration, grinding to a fine particle size is unlikely to cause acidosis but should improve starch digestibility and feed efficiency.

Grain can be either rolled or ground to reduce mean particle size. Compared to rolled grain, ground grain typically has a much larger range in particle size due to the fines generated during grinding. Hence, GMD alone, though useful, is incomplete as an index of processing. Baker and Herrman (2002) describe additional components (particle surface area; particles per gram) that can be calculated through sieving processed grain. Presence of fines and the GMD of rolled grain also will be altered by moisture content and hybrid of the grain being processed; wetter and more vitreous dried grain generate fewer fines and the particles have a larger GMD. Cereal grains that remain whole are fermented very slowly if at all either in the rumen or the small intestine. Rupture of the seed coat or perciarp exposes the starch in the endosperm for digestion. When fed as whole corn grain and chewed and ruminated by steers, less than one-third of starch that entered the intestines was digested in the intestines! This indicates that whole corn is insufficiently chewed by steers to be extensively fermented either in the rumen or digested in the intestines.

More thorough chewing of whole grains by sheep and by calves than by adult animals leads to greater starch digestibility. Certainly, field observations indicate that when whole shelled corn is fed to steers, the total diet must contain a very low amount (under 10%) roughage so that the whole grain particles will be retained in the rumen to be ruminated and fermented. The low roughage level and longer ruminal retention may explain why whole corn often results in better feed efficiency than a diet of rolled corn fed with a higher level of roughage. Though added roughage usually shortens the time that particles are retained for fermentation within the rumen, extent of ruminal separation of roughage particles from whole grain also may be important; separated grain that settles in the rumen will not be ruminated.

High moisture corn. Two factors are critical for maximum feed efficiency and ruminal starch digestion from high moisture corn grain -- adequate moisture content (preferably above 26% moisture) and a sufficient duration of fermentation. For some unknown reason(s), high moisture grain ensiled between 20 and 24% moisture results in poorer feed efficiency than either drier (rolled) grain or wetter grain. Moisture level and storage time responses have been reviewed previously (Owens et al., 1986) and demonstrated both in vivo (Jaeger et al., 2004) and in situ (Benton et al., 2004). Results from the latter trial indicate that in situ disappearance of starch in the rumen from high moisture corn (28% moisture or above) increased rapidly during the first month of storage and continued to increase substantially during the following eight months of storage, particularly with drier high moisture corn. Applying this principle, wetter high moisture corn, typically harvested first, should be fed first whereas drier high moisture corn, harvested last, should be allowed to ferment for a longer time period. This is precisely the opposite the first-in last-out system used in most upright or bunker silos!

Furthermore, an increased rate and extent of ruminal fermentation of high moisture grain stored for many months can place cattle at greater risk of acidosis even if diet composition is not altered. Because corn grain that had been reconstituted (water added and allowed to ferment) resulted in similar in situ starch disappearance and feed efficiency as corn grain that was harvested at a high moisture content, the increased digestibility of starch from high moisture than from dry rolled corn appears to be due to the fermentation process, not to kernel characteristic of corn grain harvested before it dries in the field. Because starch digestion parallels the increase in N solubility seen with fermentation time with high moisture corn grain, the fermentation process appears to solubilize protein that restricts bacterial access to starch granules of the endosperm. If proteolytic activity is responsible for solubilization of corn proteins, then the types and proteolytic activity of bacteria inherently present on the crop or added as an inoculum are likely to influence starch digestibility.

Steam flaked corn. As reviewed by Zinn et al. (2002), the degree of damage of starch and extent of denaturation of protein in flaked grain varies with processing conditions. Flake thickness and density (bushel weight) are used as quality control indices at the flaker whereas starch availability (glucose release during exposure to amylolytic enzymes) often is measured in a laboratory long after the grain is fed. The relationship of bushel weight of corn grain (from dry rolled grain through to grain that has been steam flaked at various densities) to ruminal starch disappearance is illustrated in Figure 5. Except for one of these 17 trials in which different bushel weights were fed, steam flaking or steam rolling to a lighter test weight increased starch disappearance.

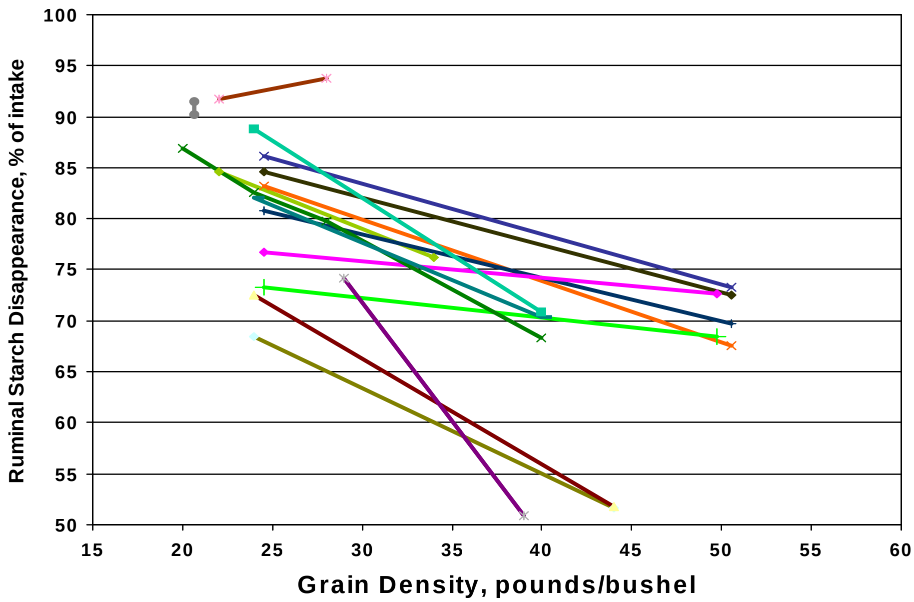

Figure 5. Impact of density of processed grain on ruminal starch disappearance. Each line represents values from a single experiment and lines connect individual diets within the experiment.

This increase in ruminal digestion with flakes of lower density and thickness was paralleled by increases in both intestinal and total tract starch digestion. Total tract starch digestion by steers exceeded 95% when flake density was below about 30 pounds per bushel. Zinn (1990) demonstrated that within a processing system, total tract starch digestion increased as flake density decreased; net energy value of steam-flaked corn was greatest when total tract starch digestion was approximately 99%. For a given mill (flaking system), he suggested that flake density should be adjusted to achieve 99% starch digestion (typically less than 4% fecal starch or about 24 pounds per bushel). But because corn flaked to a very light test weight often depresses feed intake by steers, possibly due to high rates of ruminal acid production or high acid concentrations, gelatinizing more than 50% of the starch typically is avoided. If abomasal starch from flaked grain can be digested in the small intestine, and if absorbed glucose is used more efficiently than absorbed volatile fatty acids, then optimum energetic efficiency may be reached at a slightly higher flake weight than is needed to obtain a total tract starch digestibility of 100%.

Appraising Processing Efficiency and Starch Digestibility

Methods to appraise starch digestibility vary with grain characteristics and processing method. First, energy content of a sample of cereal grain depends on its chemical composition. Most of the digested energy in cereal grains is derived from stored starch. Dilution of starch by protein and fiber, components that are less digestible than starch, decreases the net energy value of the grain. Likewise, moisture and ash do not contribute energy for animals. At the site of processing, digestibility of rolled grain can be appraised through measuring geometric mean diameter, a proxy for surface area. Because more vitreous grain yields coarser particles when rolled, digestibility of starch will be greater for specific grains (corn and sorghum grain) that are less vitreous (more floury) and grain particles with less residual pericarp attached to the vitreous endosperm. For flaked grains, thinner flakes are more rapidly and extensively digested, so flake thickness, or bulk density, serves as a useful predictor. When flaked, floury grains yield fragile flakes and more fine particles, so more vitreous hybrids are preferred. With high moisture grain, protein solubility appears serves as a predictor of protein digestibility and vitreousness appears unimportant.

In contrast to predicting starch digestion, direct measurement of starch digestibility by animals provides a "bottom line" value for determining the effectiveness of processing grain (Zinn et al., 2002). In Figure 6, total tract starch digestibility is plotted against fecal starch (percent of fecal DM) from the reviewed trials. For steers fed high concentrate diets, total tract starch digestibility was predicted quite well from fecal starch content alone. If the goal for flaking corn grain is to obtain a starch digestibility above 98%, steers should have less than 5% starch in feces providing no other sources of starch (e.g., other grains; corn silage) are fed. One also can determine starch digestibility through using some internal or external marker as described elsewhere (Correra et al., 2005). Some estimate of fecal starch or starch digestibility should prove useful for fine-tuning processing to optimize grain or corn silage-processing procedures.

For immediate recognition of corn hybrids or corn samples with superior value, near infra-red (NIR) scanning procedures have been developed by scientists for grain users to employ when selecting hybrids or grain batches for high extractable starch (HES), high total fermentables or ethanol yield (HTF), and high available energy (HAE) for feeding pigs, respectively. Such procedures are now being employed by plant breeders for selecting inbreds, for extension specialists to recommend hybrids for specific end-users, and by some grain users to assign price premiums or discounts to batches of grain. By encouraging production of specific hybrids for specific markets, such procedures can be expected to challenge the "commodity" trading of grain. As hybrids with improved feeding value are identified and developed, efficiency of livestock production will improve.

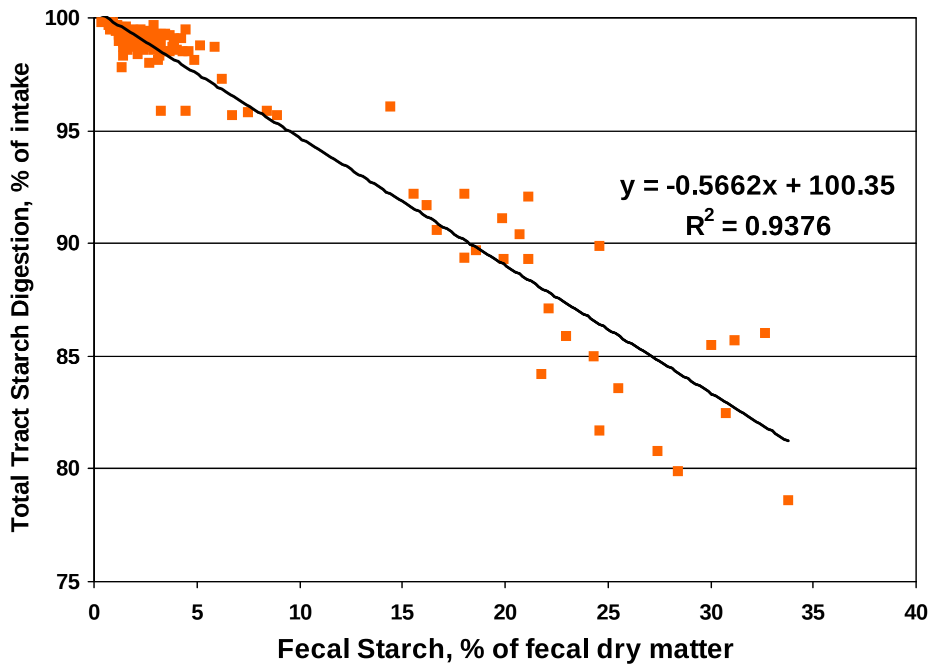

Figure 6. Relationship of total tract starch digestion to fecal starch concentration.

Roughage Selection and Level: Impact of Grain Processing

Grain processing method may alter the ideal level and source of roughage. A minimum of six different factors should be considered when selecting a roughage source and dietary level. These include the effective fiber (NDF present in coarse particles) concentration in the roughage source, potential for separation of roughage from concentrate during mixing or by the animal, separation of roughage from concentrate particles in the rumen, rate of ruminal digestion of NDF, extent of total tract digestion of the roughage source, and roughage cost. In contrast to high roughage diets where digestible fiber provides a substantial fraction of the available energy, higher cost of ME from roughage than from concentrates dictates that least cost diets will contain only minimum amount of roughage. Furthermore, extent of NDF digestion with concentrate diets is quite low. Consequently, the relative feed value (RFV) of the forage fed is less important with concentrate diets than with higher roughage dairy-type diets. Nevertheless, coarseness to enhance chewing during eating (to enhance saliva flow), to stimulate mixing of ruminal contents, and to expand rumination time remains important. For these functions, roughage sources with low digestibility (straw, cornstalks, sweet corn residue) often have value equal to high quality alfalfa or corn silage in concentrate diets. On this basis, low cost per unit of effective NDF would be a desirable economic criterion. However, additional NDF beyond that needed for prevention of acidosis can increases intake of both feed and net energy of high concentrate diets (Defoor et al. 2002; Owens et al., 2002), probably through increasing ruminal pH or shifting site of digestion from the rumen to the intestines. However, when effective NDF levels exceed about 10% of diet dry matter (about 25% corn silage or alfalfa hay) of concentrate diets, rate of gain will be depressed. The relative cost of energy from roughage versus concentrate must be considered when determining whether this much roughage should be fed; the optimum roughage level will change with the price of roughage versus concentrate. Because whole and coarsely rolled corn as well as barley and oats have "built-in" roughage characteristics, less NDF from roughage needs to be added to such diets than when diets contain less fibrous grains or when grain is processed extensively.

To reduce separation of roughage from grain during feed mixing and avoid sorting by cattle, a roughage should have a small particle and be sticky (being wet itself or be with other wet ingredients in the diet). Limiting feed intake also can reduce feed sorting. Unfortunately, reducing particle size also reduces the effectiveness of the NDF of roughage. Separation of roughage from concentrate particles in the rumen also can occur. For example, alfalfa hay tends to separate from dense grain particles in the rumen so that grain will not be ruminated; in contrast, cottonseed hulls mix readily with grain particles in the rumen so that grain particles are ruminated to enhance ruminal starch digestion. Such rumination of grain particles is most important when grains are fed whole or coarsely rolled. The higher the rate of ruminal NDF digestion, the greater the feed intake by lactating cows, presumably because rapid clearance of NDF reduces bulk fill of the rumen. As ruminal capacity does not limit feed intake with concentrate diets as it may with roughage diets, rapid NDF digestion provides no advantage for cattle fed concentrate diets. In fact, to stimulate rumination between meals, a LOWER rate of NDF digestion may be preferable with concentrate diets. High quality forages should be reserved for high producing dairy cows with lower quality forages being suitable for concentrate-fed cattle. In either case, roughage should be reserved for ruminants. Vegetarians please take note.

Finally, by acidifying ruminal contents so that pH is below that required for growth and activity of cellulose digesting bacteria, more extensively processed grains will depress digestibility of ADF (cellulose plus lignin). This supposedly causes a "negative associative effect" wherein a mixed diet (concentrate plus roughage) results in depressions of intake, digestibility, and efficiency of feed use below the mean of a high concentrate and a high roughage diet. To avoid this effect, some cattle feedlots to use a "two phase" feeding system in which a high roughage diet is fed during the first half of the feeding period followed by a high concentrate diet during the second half of the feeding period. Because a low ruminal pH depresses digestibility more for ADF than for NDF (hemicellulose plus ADF), the optimum ratio of NDF to ADF for a forage may differ with grain processing. With extensively processed grain, a low ADF to NDF ratio would be preferred whereas with whole or rolled grain, roughage with a greater ADF to NDF ratio can be tolerated because cellulose digestion will depressed less. As ratio of ADF to NDF increases with maturity of grasses and legumes, early maturity forage higher in RFV would be preferred with processed grains while lower quality more mature forage and mature corn silage should have greater comparative value when diets contain whole or rolled grains. This might explain why high quality alfalfa often is considered a "sacred cow" at feedlots where grain is extensively processed.

Anecdotes about Holstein Steers

Conversations with feedlot managers and feedlot nutritionists who supervise feeding of cattle with diverse genetic and environmental background often provide insights that have not been critically tested and may or may not prove accurate. Whether or not such comments are correct, these anecdotes deserve some attention as they may impact management and feeding recommendations related specifically to Holstein steers.

"Holstein steers have excessive intakes. Some pens consume over 35 pounds of dry matter daily of rolled corn per head; that's just too much. You need to 'burn' Holsteins at the start of the feeding period with hot diets or they will eat you out of house and home." Data from Hicks et al. (1990) indicates that Holstein steers will eat about 2.4 pounds more feed per day than typical beef steers, so high feed intakes can be expected for Holstein steers. With higher feed intakes and high rates of passage, starch digestibility from dry rolled corn or whole corn will be low and to achieve enough energy for a high rate of gain, cattle will eat even more feed. Consequently, the benefit from thoroughly processing grain by flaking or high moisture preservation should be greater for Holstein steers than for typical beef steers.

"Long-fed Holstein steers 'stall out' after 200 days on feed. When we see intakes decline, we drop back a ration (add more roughage to the diet) for several weeks and then bring them the Holsteins back up to the top (high concentrate) ration again." In a feedlot, Holstein calves often are fed concentrate diets for 360 days, over twice as long as typical beef steers. The likelihood of digestive disorders is proportional to the number of days fed, so a long-fed Holstein is more likely to encounter problems. Special care to avoid acidosis and maintain a healthy ruminal wall, possibly by feeding a higher roughage level, is likely to have greater economic benefit with long-fed Holsteins than with shorter-fed beef steers.

"We put 30% fewer steers in a pen of Holsteins than of beef steers because otherwise the Holsteins will be wading in mud." Water intake is much greater for Holstein cows than finishing steers. Perhaps generations of selection of milk production has enhanced water intake by Holstein cattle, and urine output is proportional to water intake. If water intake is high, does this flush more nutrients to the intestines for absorption and decrease digestibility? If water intake actually is greater for Holstein than beef steers, special attention to water supply, water quality, and pen surface conditions for Holstein steers is warranted.

"On a live basis, and particularly on a carcass basis, Holsteins have lousy feed efficiency." Based on one comparative slaughter trial, Holstein steers required 23% more feed to maintain body energy than Hereford steers (Garrett, 1971). Other estimates indicate that maintenance energy requirements are 7 to 20% greater for Holstein or Friesian cattle than for Angus or Hereford steers. The NRC (1996) estimates that the maintenance energy requirement is 20% greater for Holstein (as well as Jersey and Simmental) than for Angus and Hereford cattle. Some of this difference may be associated with greater physical activity. But more likely, maintenance requirements are correlated with genetic potential for growth or milk production (and perhaps to the relative mass of high-maintenance internal organs including the liver and digestive tract). In addition, Holstein steers tend to deposit more of their fat omentally (around the intestines) and less subcutaneously than beef breeds. At harvest, omental fat is removed whereas much of the subcutaneous fat remains with the carcass; this accentuates the difference between breeds when the amount of consumed energy retained in the carcass is measured. Furthermore, deposition of omental fat is enhanced when glucose absorption from the small intestine is increased. Hence, grain-processing methods that decrease intestinal glucose supply should be preferred for Holstein steers (leading to a preference for high moisture over steam flaked grains.) Having less subcutaneous fat deposition is an advantage for carcass processing, reducing the need for and loss from trimming external fat from carcasses.

Summary

- Grain sources differ in their response to processing. For maximum starch digestion by cattle, corn and sorghum grain must be processed, but for barley and wheat, limited processing appears adequate.
- Steam flaking or fermentation (high moisture storage) increases the extent of starch digestion of corn and sorghum grain both in the rumen (of dietary starch) and in the intestines (of starch reaching the small intestine).
- Decreasing flake weight of corn increases starch digestion at all sites, particularly in the small intestine; to maximize ruminal starch digestion; however, thinner flakes will increase the likelihood of ruminal acidosis.
- Including high amounts of forage in the diet speeds passage of grain through the rumen; a shortened ruminal retention time limits the extent of ruminal digestion.
- Digestion of starch reaching the small intestine appears limited by accessibility of the starch; coarse particles, as from dry rolled and whole corn and sorghum grains, are poorly digested in the intestines.
- In addition to increasing digestion of starch from corn and sorghum, more extensive processing increases digestion of non-starch components and decreases methane loss.
- Different hybrid characteristics are desired for different processing methods. For whole and dry rolled corn or sorghum grain, starch is not fully digested (5 to 15% remaining undigested. Very fine grinding of grain with a floury endosperm, thin or loose pericarp, and low amylose content all help maximize starch digestion. For high moisture grains with adequate moisture content (over 28%) and adequately processed steam flaked grains, starch digestion usually exceeds 98%. This means that the concentration or digestibility of components other than starch (NDF, protein) is responsible for differences (1 to 3%) in total tract energy digestibility among hybrids.
- Fecal starch content, being correlated with starch digestibility (R^2 = 0.73 to 0.94), can be used to appraise efficacy of processing, but starch digestibility is predicted more precisely from analysis of feed and feces for N and starch.

- The ideal level and source of roughage can vary with the grain processing method used.
- Ideal traits for a hybrid differ among segments of the livestock or agricultural industry. For livestock producers, the primary concern is feed efficiency; for corn producers, it is grain yield and production cost; for farmer-feeders, both grain yield and digestibility must be combined if one seeks to maximize beef production per acre of grain produced.

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