Enhancing the Value of Corn Grain in Dairy and Beef Diets through High Moisture Harvest or Steam Flaking

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Take Home Message

- Starch is the primary energy source in corn grain.
- Compared with dry rolled or ground grain, thoroughly processed (steam rolled or flaked; fermented high moisture) grain is much more digestible.
- Processing grains requires more planning, labor, expense, and facilities than dry rolling or grinding grain.
- When grain prices are high, economics can justify more extensive and expensive grain processing.
- For maximum digestion, high moisture corn (HMC) must contain more than 26% moisture (the higher the better), be rolled or ground into storage, and be held in storage a minimum of 60 days (the longer the better).
- Harvest of grain with more than 35% moisture reduces yield of grain dry matter.
- Harvest of grain with less than 26% moisture reduces yield of grain dry matter.
- For maximum digestion of starch from steam rolled or flaked grain, flaked grain should have a bushel weight below 30 pounds per bushel (the lower the better).
- Bushel weights below 28 pounds per bushel often decrease feed intake and performance for cattle fed high concentrate diets but not for lactating cows fed diets higher in forage content.
- Extent of starch digestion by dairy cows and feedlot cattle can be calculated reliably based on the concentration of starch in fecal dry matter.
- The net energy value of grain is correlated closely with starch digestibility of the grain.

Introduction

Cereal grains are processed for various reasons. Processing can make grain more palatable (e.g., buttered popcorn), decrease the batch-to-batch variability in digestion of grain (that causes intake fluctuations characteristic of sub-clinical acidosis), serve as an integral link in crop production (early grain harvest expands the time available for field work or for managing other crops), and simplify grain storage and handling. The primary nutritional reason that cereal grains are processed is to enhance availability of energy (particularly starch) and nutrients from grain. Reducing the size of grain particles serves to fracture the seed coat and increase the surface area exposed for digestion. Additional heat and pressure gelatinizes starch and increases the availability of more vitreous starch for microbial and enzyme digestion. Both particle size reduction and gelatinization can be used to increase the rate of starch digestion and alter the site where starch is digested (rumen versus intestines). Processing also can simplify mixing of grain with other diet components, help avoid segregation of ingredients during feed mixing, and reduce ingredient sorting by ruminants.

Corn grain is the primary grain fed to confined ruminants within the US, typically providing over 50% of the digested energy for lactating cows and 85% of the digested energy for finishing cattle. Digestibility of corn grain and thus the efficiency with which the energy from corn grain is used by ruminants varies with the extent to which grain is processed. Grains can be fed after being processed to a very limited degree (fed whole or ground or rolled) or quite extensively (steam rolled or flaked; fermented to form high moisture corn). More extensive processing typically involves additional equipment, time, and cost. As outlined by Zinn et al. (2011), the two main barriers to digestion of grains are 1) the seed coat and 2) vitreousness of the starch. The seed coat must be disrupted to expose the internal kernel components to attack. Particle size reduction to fracture the seed coat can be achieved by rolling or grinding the grain before it is fed. Alternatively, by chewing, rumination, and churning in the rumen the animal itself will reduce the particle size of fed grains and increase digestibility. Young and small ruminants typically chew their feed quite thoroughly so the grain in "creep" feeds often is not ground. But older animals, particularly those accustomed to grazing or those with high feed intakes or fed high forage diets, usually gulp their feed without chewing it extensively. And because dense particles settle in the rumen, some grain particles will escape rumination. Consequently, for older or adult ruminants, more extensive grain processing is needed to obtain maximum starch and energy digestibility. Conversely, more extensive grain processing, through increasing rate and extent of ruminal digestion, also increases the likelihood of metabolic disorders including acidosis. Achieving maximum starch digestion while maintaining a low incidence of metabolic disorders presents a persistent management challenge for livestock producers and nutrition consultants.

Differing from other cereal grains (wheat, oats, barley), corn and sorghum grain encase a sizeable portion of their endosperm starch in a hard or vitreous form that protects the starch from water damage and attack by enzymes produced by insects and microbes. Consequently, extensive physical or chemical processing is needed to disrupt this vitreous starch to achieve maximum digestion of starch (energy) from either corn or sorghum grain. Readers with deeper interest in grain processing methods, their scientific basis, and practical implications can find much more detailed information within 29 different articles included in the Grain Processing Symposium (2006) plus additional articles by Firkins et al. (2001), Huntington (1997), Huntington et al. (2006), Owens (2005), Owens et al. (1997), Zinn and Owens (2008) and Zinn et al. (2011).

Processing methods

Grains are fed to ruminants in widely diverse forms. The forms most prevalent include: a) whole (unprocessed); b) mechanically processed either b1) without heat to form rolled or cracked grain with particles that will range from coarse to fine or b2) with steam heat forming steam rolled or flaked grain; and c) fermented using moisture either c1) present in the grain at harvest forming high moisture grain, earlage, snaplage or silage or c2) added to dried grain forming reconstituted grain. Grain also can be processed by other systems (e.g., roasted, popped, extruded), but because equipment for these processes is quite expensive, such products generally are marketed for pets and humans, not fed to ruminants. The three primary effects achieved by various different processing methods include: 1) reduction in particle size, 2) solubilization of protein and some starch (during fermentation) and 3) gelatinization of starch and denaturation (melting) of proteins when steam is applied. The more extensive processing methods (b2 and c) that substantially increase digestibility of starch and other components of grain usually require increased input of time, planning, cost, equipment or facilities, and effort when compared with grinding or rolling of dry grain. Indeed, grain processing will not prove economically viable when the price of grain is low, when processing cost is high, or when fecal waste has an economic value (back when swine survived on feedlot waste or, today, when waste is fed to biogas digesters). But when grain price is high, more extensive grain processing methods can be justified economically. Specific grain harvest and processing methods also may have ancillary benefits. These include: reduced variability among grain batches in starch availability (to reduce the incidence of metabolic disorders); earlier harvest of high moisture grain (to reduce field loss of grain and earlier fall field work or planting of second crops or fall field work); esoteric (visual appeal of flaked grain to cattle owners and feed buyers); and competitive (high feed efficiencies from flaked grains often are preferred by cattle owners when selecting a custom feedlot). Economic return from and thereby commercial interest in more extensive methods of grain processing automatically expands when the price of grain is high.

Corn processing economics

The increased economic value of various methods for grain processing can be estimated from the amount that either starch digestibility or net energy content is increased by processing. The degree to which energy availability or starch digestibility is increased by processing for dairy and beef cattle has been summarized in various publications (Owens et al., 1997; Firkins et al., 2001; Zinn and Owens, 2008; Zinn et al., 2011; NRC 1996; 2001). Such estimates have been derived either by direct comparisons of a single batch of grain or by calculating the net energy value of the grain from cattle performance and feed intake. Starch digestion and net energy values as well as the advantages from processing are presented in Table 1. Obviously, the benefit from processing varies with the basis used (rolled versus ground grain) as well as the final processed form of grain (flaked versus rolled for steam processed grain; ground versus rolled into storage for HMC).

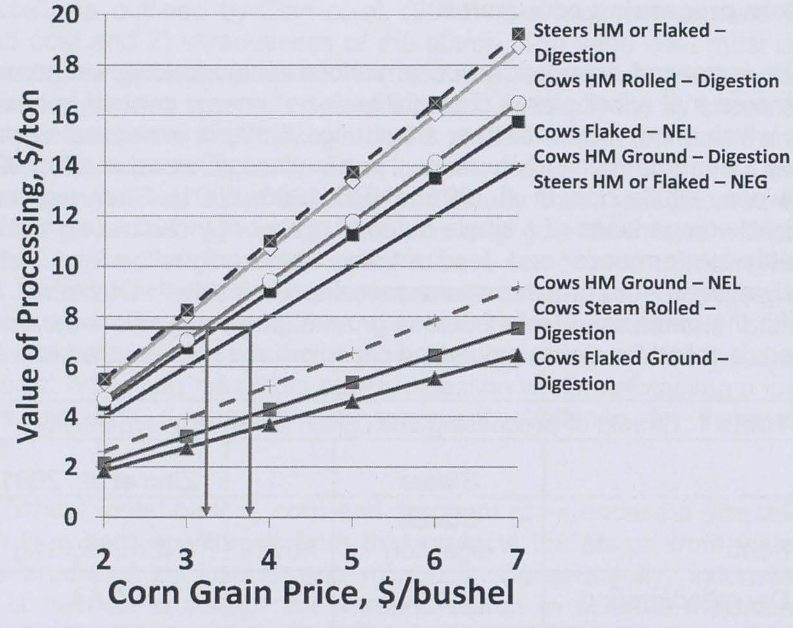
Table 1. Effects of processing corn grain on energy availability.

	Steers		Zinn et al., 2001		NRC 1996	
Form	Starch digestion	Adv,%	NEm, Mcal/kg	Adv,%	NEg	Adv,%
Dry rolled/ground	89.3	-	2.14	-	1.50	-
Steam rolled/flaked	99.1	11.0	2.46	15.0	1.62	8.0
High moisture	99.2	11.1	2.31	7.9	1.62	8.0
	Lactating cows	from	Firkins et al., 2001			
	Starch dig-Rolled		Starch dig-Ground		NEL	
Dry rolled/ground	85.1	-	90.7	-	1.91	-
Steam rolled/flaked	88.8	4.3	94.1	3.7	2.09	9.4
High moisture	94.2	10.7	98.9	9.0	2.01	5.2

Generally, the digestibility and NE advantages from processing are greater for steers than for lactating cows. For steers, the energy advantage over that of rolled corn was similar for both flaked and HMC. But for lactating cows, optimum starch digestibility favored high moisture over flaked corn while the improvement in net energy for lactation favored flaked corn over HMC. This discrepancy indicates that starch digestibility may explain most but not necessarily all the benefits from grain processing, probably because starch digested in the small intestine has greater energy value for lactation than starch fermented in the rumen (McLeod et al., 2006).

Based on these energetic advantages, the economic value ($ per ton processed) of flaked or HMC over dry rolled corn can be calculated at various corn grain prices (Figure 1). Economic value was estimated as the value of the grain that could be saved (replaced) by processing.

Figure 1. Value of different methods of grain processing for feedlot or dairy cattle.



The cost of processing must be subtracted from these economic values to calculate the economic return from processing. The cost of flaking corn grain at feedlots will vary with the cost of equipment and energy. In 2006, Macken et al. and Peters estimated the fixed plus variable costs of flaking corn to be $7.21 per ton. Based on this value, flaking appears economical on a net energy basis when the price of corn grain is above $3.80/bushel for feedlot cattle and above $3.25/bushel for lactating cows (vertical lines of Figure 1). Surprisingly, HMC had a NEGATIVE cost of $4 per ton of grain stored! This value is negative due the low seasonal and regional price of corn at harvest, the low cost for transfer and delivery of local grain, and avoiding the need for drying and commercial storage of grain. Because it had a negative cost, harvest and storage of HMC appears justified at any grain price! But once ensiled, fermented grain has no market besides animal feed. These estimates are based on numerous assumptions about fixed and variable costs, feedlot or market size, and local availability of harvested high moisture grain.

What Limits the Digestion of Energy from Cereal Grains?

Factors limiting digestion of corn grain were outlined clearly by McAllister et al. (2006), Zinn et al. (2011) and by Hoffman et al. (2012). To digest the carbohydrate in cereal grains, enzymes produced by microbes or animals need to access the carbohydrate. Access barriers can be physical, like the pericarp that surrounds the entire kernel, or though water exclusion (anhydrousness), like vitreous starch. The seed coat or pericarp can be readily breached physically through grinding or abrasion either before feeding or later as a ruminant chews (during eating or rumination) or rumen mixing fractures the moistened particles. Areas within a kernel that are anhydrous inhibit penetration by the fluids that transport microbes and enzymes. These anhydrous areas can be degraded only partially by fine grinding; more extensive grain processing is needed to fully access the vitreous starch of dried corn kernels.

Pericarp

Being a seed, the corn kernel is protected from moisture uptake and attack by insects and microbes by the pericarp. Kernels or seeds from either grains or weeds with an intact seed coat or pericarp usually pass through the digestive tract of ruminants unscathed. By remaining viable and spread through feces, an intact pericarp helps feral animals spread plant species widely. For corn kernels to be digested, the seed coat must be fractured to permit moisture, microbes, and enzymes to enter. But even after being coarsely rolled or ground, particularly when dry, some starch still adheres to the pericarp and, being partially guarded from attack, is digested less completely. Stress cracks in the pericarp can be induced by drying grains at a high temperature or by premature grain harvest. Genetic factors also influence pericarp thickness and its ease of removal, a step important for industrial isolation of kernel components.

The pericarp is primarily fiber or NDF. The NDF of a feed always is less digestible than its cell contents. Fortunately, most cereal grains are low in NDF with corn grain having about 10% NDF. An egg shell, as a proportion of egg weight is less for a large egg than for a small egg. Likewise, large corn kernels have less pericarp and less NDF than smaller kernels. This gives larger kernels more net energy has been observed in finishing steers by Jaeger et al. (2006). Unfortunately, hybrids with a large kernel size often are not commercialized due to problems expected with seed handling and planting equipment. Kernel size and weight increase markedly as kernels mature, increasing by up to 35% from an immature (half milk-line stage) to maturity (black layer stage). Indeed, yields of dry matter as high moisture grain or corn silage increase by about 3% and 1.3% per day, respectively, during this 10 to 14 day window when grain fill occurs. Consequently, premature harvest (above about 35% grain moisture) will reduce the yield of both grain and silage drastically. However, delaying harvest until grain contains 28% moisture or less or is fully dried in the field also reduces grain yield due to field and harvest losses.

Vitreous endosperm

Starch typically comprises about 72% of the dry weight of dent corn grain, most of which is found in the endosperm. Therein starch exists in two distinct granule types – a vitreous (hard, horny) type where individual granules are tightly packed in a slowly degraded protein (zein) matrix, and a floury type where granules are loosely packed. Although different zein types exist, zeins (also called prolamins) are rich in proline and thereby are insoluble in water or buffer solutions. Often half of all the protein in mature dent commercial corn hybrids is zeins. This means that of the starch in commercial corn hybrids, some 55 to 75% is vitreous. Yet, specific selected strains can range from 0 to over 80% vitreous starch. Quality protein (high lysine) corn hybrids preferred for humans and nonruminants have no vitreous starch, but because they consequently have a high proportion of floury starch, they typically are fragile and have low test weights, factors that can complicate grain handling and result in price discounts for marketed grains. As a result, hybrids with low test weight (and a high proportion of floury endosperm) often are not commercialized by seed companies. In contrast to floury hybrids, flint hybrids prevalent in Central and South America and Europe usually have 80% or more of their starch in the vitreous form. Generally, vitreousness of starch increases with kernel maturation and with the protein content of grain (and thereby the N fertility of soil).

When ground, hybrids that have a higher proportion of starch of the floury type yield more powdery fine particles than more vitreous grain. Because smaller and finer particles are digested more rapidly in the rumen, the extent of starch digestion in the rumen (and likely in the total digestive tract) often is greater for floury hybrids, particularly when dried grain is coarsely ground or rolled. To achieve a similar digestibility, more vitreous grain types must be rolled or ground more finely (to a smaller particle size) than floury grain types. Fine particles that may be flushed through the rumen and digested in the small intestine have an energetic advantage for the animal, but because small particles also have an increased surface area for microbial attack, the fine particles are fermented rapidly in the rumen. Although a faster rate of digestion often increases extent of starch digestion, it also increases the potential for acidosis. When various grain samples were dry rolled and fed to steers, hybrids with a higher proportion of floury starch produced superior feed efficiencies by steers (Jaeger et al., 2006) presumably due to a greater total tract digestibility of starch from dry rolled floury hybrids than dry rolled flinty hybrids as noted by Corona et al. (2006). However, extensive processing, either by steam flaking or fermentation to yield HMC, obliterates the difference between floury and vitreous hybrids in starch digestibility based on trials with steers fed flaked (Corona et al., 2006) or HMC (Szasz et al., 2007). Yet, if corn is merely coarsely dry rolled corn, total tract starch digestion generally is greater for samples of corn grain that are more floury. Bushel weight of grain often is negatively related to kernel vitreousness. Thereby, corn grain with a low test weight often has greater starch digestibility than grain that exceeds the 54 pound bushel minimum for USDA # 2 corn when the grain is not extensively processed prior to feeding.

Amylose percentage

Glucose components of starch can be linked either in a linear fashion (amylose) or in a branched, tree-like structure (amylopectin). Being linear, amylose can form crosslinks (retrograde). Neither amylose nor retrograde starch is fermented or digested as readily as the branched amylopectin. The starch in most commercial dent corn grain is 25 to 29% amylose. But hybrids with 50 and 70% amylose are grown for industrial use. In contrast, waxy hybrids have no amylose (only amylopectin). Because amylopectins form gels when cooked, they are used in manufactured food products. When dry rolled or ground for feeding cattle or when fermented to produce ethanol, waxy grains have a slight efficiency advantage, being more rapidly and extensively fermented. Again, this advantage for waxy grain disappears when the grain is steam flaked. When they are cooked, waxy grains being steam flaked form gels that can adhere to flaking rolls. Waxiness is a recessive trait lost with cross-pollination. Also, because waxy hybrids usually have lower grain yields than non-waxy hybrids, only a limited amount of waxy grain hybrids are grown in the US, typically under contract with a food processor.

Resistant starch

When exposed to moisture and heat (as when cooked and crushed or flaked), starch granules swell, expand, and explode forming gelatinized starch. The fraction of total starch that is gelatinized during steam flaking varies with processing conditions, but for feeding, the ideal extent of starch gelatinization suggested by consultants is between 40 and 60%, the lower value being needed for maximum ruminal digestion while the higher limit is the point above which ruminal digestion becomes extremely rapid or the extent of retrogradation or formation of resistant starch increases. Holding flaked grain warm after flaking increases the amount of retrograde starch formed. During retrogradation, chains of amylose become associated physically and harden becoming insoluble in water. This reduces the accessibility of the amylose to starch-digesting enzymes. Because of its low digestibility, retrograde starch, as found in stale bread, often is considered "indigestible" and, though useless for most non-ruminants, is of commercial interest in the diet food industry serving humans! Retrograde starch resists enzyme attack and fermentation by yeast, two common methods used at feed analysis labs to estimate availability of starch for ruminants. Yet, ruminal microbes still appear to attack retrograde starch (Ward and Galyean, 1999). Nevertheless, field observations indicate that rapid cooling of flakes following flaking, as with an airlift system to transport grain being flaked, usually produces flaked grain with less retrograde starch (McMeniman and Galyean, 2009). Field observations indicate that rapidly cooled flakes may be used by cattle more efficiently than flaked grain dropped into a dragline system and stored warm in a pile or bin for several hours after it is flaked.

How can rate and extent of starch digestion be increased?

Several factors limit the extent that animals digest starch. By disrupting the pericarp, coarse rolling or grinding opens the kernel and allows microbes or enzymes to enter. Considering that the exposed surface area limits the extent of fermentation, the size of particles generated during processing is a pre-eminent factor. Particle size typically is measured through sieving grain through multiple screens that differ in hole diameter. Particle size typically is reported as the mean particle size or geometric mean diameter (GMD), a value calculated from the proportions of grain retained on specific sieves

(Baker and Herman, 2002). However, the exposed surface area per unit of weight is greater for smaller than for larger particles, a fact not well reflected in the mean particle size value alone. For example, the particle size distribution for hammermilled and roller milled corn differs markedly (Figure 2) even though these two corn samples had an identical mean particle size (740 to 800 microns)! The extremely small and large particles are of concern. Particles with a very small size have a very large surface area exposed for microbial attack, so the proportion of fine particles might be used as an index of the potential of a sample to cause ruminal acidosis. On the other extreme, coarser or large particles are have less surface area exposed and thereby are less rapidly and will be less completely digested when time in the rumen is limited. Ferreira and Mertens (2005) indicated that corn particles from silage larger than 4.25 mm were poorly digested by cattle pointing out the need for kernel processing drier corn silage. Generally, starch from coarser particles is less rapidly and fully digested when exposed to rumen fluid in vitro or in situ. Based on these observation, mean particle size alone, ignoring the distribution of particles, appears incomplete as an index to predict digestibility of starch.

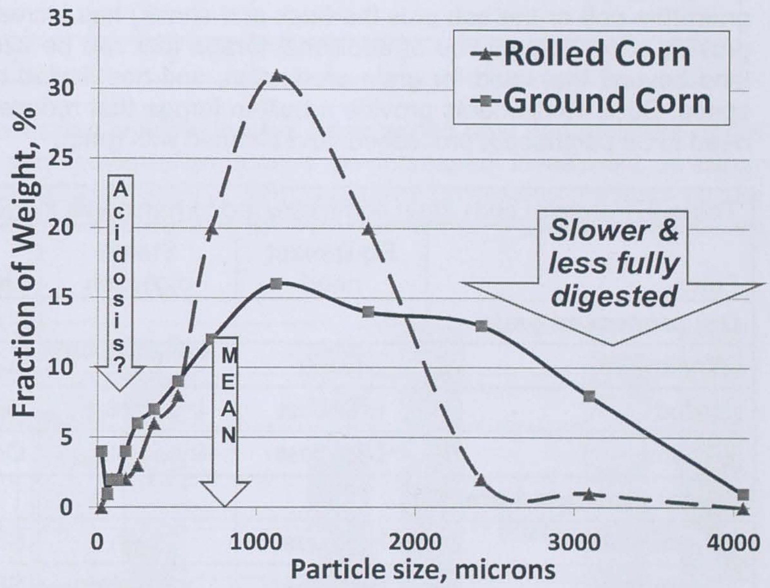


Figure 2. Particle size distribution of corn rolled and ground to the same mean particle size. Data from McKinney, 2006.

Additional factors beyond mechanical setting of grain processing equipment and grain vitreousness influence the distribution in particle size of rolled or ground grain. These include moisture content of the grain being ground (Zinn et al., 2008), hammermill speed and screen type (uniform versus graduated), presence of stress cracks in the pericarp, and moisture distribution within the kernel. To monitor and control processing of HMC into storage, progressive feedlots (Hicks and Lake, 2006) regularly screen the grain being processed and adjust grain processing to both reduce the number of particles held on a large screen (above a certain size) and reduce the number of particles that pass through a fine screen (to reduce the prevalence of fine particles). Unfortunately, very few literature reports provide particle size distribution data but instead merely report geometric mean particle size as an index of particle size.

Based on the relationship between starch digestibility by lactating cows and physical measurements (corn grain particle size, moisture content, prolamin content of processed grain), dairy scientists at the University of Wisconsin (Hoffman et al., 2012) devised a method for predicting the starch digestibility of corn samples called Relative Grain Quality. Numerous studies with lactating cows indicate that starch digestibility by lactating cows is markedly greater when corn grain was rolled or ground to a smaller mean particle size. In contrast, a summary of studies with feedlot cattle detected no impact of mean particle size on starch digestibility of corn grain. Although no specific reason for this difference is readily apparent, most of the studies with feedlot cattle used rolled grain while many dairy studies used hammermill processed grain. Furthermore, ruminal retention time is considerably longer for feedlot cattle than dairy cows because feedlot cattle have lower feed intakes and lower dietary fiber levels. Other ruminal conditions (pH, stratification, extent of rumination) also differ, and lactating cows may chew their feed less extensively to reduce particle size than feedlot cattle do.

Impacts of grain processing on site and extent of starch digestion

Many commercial feedlots blend a mixture of processed grains in an attempt to improve feed efficiency through optimizing site of digestion, to reduce particle segregation of the diet, to match grain needs with the supply of grain that can be harvested, stored, or processed, and to take advantage of seasonal price swings. Equipment needs, starch digestion, and limitations of various processed grains are itemized in Table 2. Interest in harvesting additional grain components with grain (the cob or the cob plus the husk and shank) has increased recently because these products provide a low-cost source of additional forage that can be useful in the diet, requires no additional land beyond that used for grain production, and has limited need for added equipment or storage space. Such components provide a built-in forage that reduces the quantity of roughage feeds that need to be purchased, processed, and blended with grain.

Table 2. Forms of corn grain commonly fed to ruminants in the U.S.

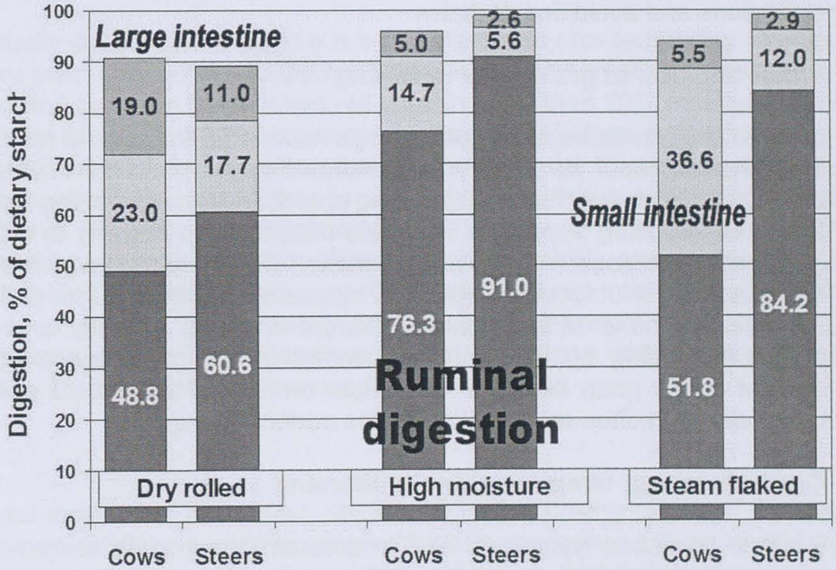
Form	Equipment need	Starch digestion	Limitations/Recommendations
Dry processed grain			
Whole	None	Low	Avoid fines; Limit forage level
Rolled	Low cost	Incomplete	Gives uniform particle size
Ground	Low cost	Incomplete	Compatible equipment
Steam processed grain			
Steam rolled	High cost	High	Short shelf life if not dried
Steam flaked	High cost	Very high	Short shelf life if not dried
Fermented grain			
High moisture corn	Low cost	High	Silo space needed
Reconstituted corn	Low cost	High	Silo space need; fermentation losses
Ear (grain & cob)			
Corn & cob meal	Low cost	Incomplete	Adds fiber; more energy per acre
High moisture ear corn	Low cost	High	Supplies fiber but silo space needed
Shucked ear (Ear+husk)			
Snapped corn	Low cost	Incomplete	Additional fiber supplied
Snaplage	Low cost	High	Extra fiber but more silo space needed

Specific responses of grains to various processing methods and their effects on rate and extent of digestion were outlined in 1999 by Rowe et al. (Table 3). As discussed above, more extensive processing through sequentially disrupting the pericarp, the endosperm matrix, and individual starch granules sequentially increases both the fermentation rate and intestinal digestion of starch.

Table 3. Effects of various processing methods on kernel structure and digestion as modified from Rowe et al., 1999.						
Processing method	Disrupts pericarp	Reduces particle size	Disrupts endosperm	Disrupts starch granules	Increases fermentation rate	Increases intestinal digestion
Dry rolling	+++	+	-	-	++	+
Grinding	+++	+++	-	-	++	+
Steam flaking	+++	++	+++	+++	+++	++
Extrusion	+++	-	+++	+	++	++
Pelleting	+++	-	+	?	+	++
Ensiling	+	-	++	-	++	+
Micronizing	+	+	++	?	?	++
Popping	++	-	++	+++	?	+++
Protease	-	-	?	?	++	?

More extensive methods for grain processing typically involve either added heat and moisture or the fermentation process. Both flaking and fermentation require an increased investment in either equipment or in facilities for storage as noted in Table 2. Effects of three processing methods on site and extent of digestion averaged across measurements from numerous digestion studies are presented in Figure 3.

Figure 3. Influence of processing on site and extent of starch digestion by dairy and feedlot cattle from Owens and Soderlund (2006) and Soderlund and Owens (2006).



Regardless of whether the grain was dry rolled, high moisture, or steam flaked (Figure 3), the total extent of starch digestion (sum of starch digestion in the rumen, small, plus large intestine) is greater for steers than for dairy cows. The fraction of dietary starch digested in the rumen also is greater for steers than for dairy cows, but the fraction digested in the small and large intestine usually is greater for dairy cows than for feedlot animals. The fraction of starch digested in the rumen is less with steam flaked than HMC. Because a portion of starch digested in the rumen is lost as methane and a portion of that digested in the large intestine is lost due to fecal excretion of microbes, the ideal location for energetic efficiency is the small intestine. Yet, for synthesis of microbial protein that can be digested and used by the animal, starch must be digested within the rumen. Risk of acidosis is less with dry rolled than processed grain so feed management must be more finely tuned when feeding high moisture or flaked grain. Consequently, more frequent meals and higher fiber diets as well as coarser particle size and blending of grains and a higher degree of bunk management is need when highly processed grains are being fed.

The flaking process

Mechanics of steam flaking were outlined by Zinn et al. (2002) and discussed by Armbruster (2006) and Drouillard and Reinhardt (2006). To form flaked grain, steam-heated moist grain is pressed between hot corrugated rolls yielding individually pressed kernels that appear similar to corn flakes, the breakfast cereal. Ideally, each kernel forms a single flake. However, flakes will fraction depending on moisture content, size of the germ, steaming time, vitreousness of the grain, and the vigor that grain is mixed with other diet components. Though flake breakage distracts from the physical appearance of the product and when mixed in a diet can yield fine particles that may separate from other components of the diet and increase the incidence of acidosis, the nutritional value of flaked grain was not reduced by extensive mixing that extensively fractured the flakes (Sindt et al., 2006). The gap between flaking rolls or pressure is set so that all kernels are crushed to an ideal degree. Therefore, a uniform kernel size for flaking is desired. Otherwise, small flat kernels may not be sufficiently processed. Large particles typically are scalped from the grain before flaking and re-added to the flaked grain. Removal of metal is essential to avoid damage to the flaking rolls. Because large, resilient flakes appear desirable to the humans that manage or own cattle, and because more vitreous hybrids generate fewer fines, many flaking operations specify a minimum test weight (> 56 pounds per bushel) for grain being purchased. Feedlots often specify specific hybrids to their local grain growers based on similar kernel and flaking characteristics to simplify flaker operations and avoid fine particles.

Water addition to grain prior to flaking

In most modern flaking systems, grain is moistened for several hours up to 24 hours before flaking. This allows deeper penetration of moisture into the grain than simply spraying a water solution on the grain later as it enters the steaming chamber. Various wetting agents (surfactants) can be added to the water being applied to the grain that, through helping to disperse any waxy coating of the grain, may increase rate of water uptake. Commercially available surfactants include SarTemp, EzFlake, and Nutrichem. Typically, moisture content of the grain mixture entering the steam chamber is above 18%. Because different amounts of water and surfactant solution need to be added depending on the moisture content of the grain, automated systems to sense moisture content of the grain and add the proper amount of water and surfactant to the grain have been developed and often are provided by the surfactant supplier.

Grain steaming, tempering, or conditioning

Grain to be flaked typically is held in a steam chest to be tempered for several hours to heat the grain and add additional moisture to the grain. Steam can be generated through a traditional boiler or by injecting water directly into exhaust from a flame and pumping this complete mixture into the steam chest. Chests are designed to avoid channeling so that all portions of the grain added will exit at a similar time.

Flaking the steamed grain

The hot steamed grain at 20 to 22% moisture is pressed between two rollers to form flakes. Roll or pin feeders immediately above the flaking rolls spread the grain across the full length of the flaking rolls. The flaking rolls usually are 18 to 24 inches in diameter and 36 to 54 inches long and have surface corrugations (12 to 16 per inch) with rounded or sharp tops that grasp kernels and pull them through the rolls. Sharper grooves reduce the thickness of flakes. Typically, electric motors turn the flaking rolls. Corn flaking is a very noisy process, but surprisingly flaking of sorghum grain is relatively quiet. Until the flaking rolls become hot, grain will not be gelatinized, so a warm-up period often is needed before the flake quality reaches its optimum. Consequently, flakers should be operated as many hours per day as feasible to dilute the amount of low quality flakes produced during this warm-up period. With coarser flakes, the temperature of the flakes dropping from the rolls usually is above 190 F but with thinner flakes the temperature usually exceeds 205 F. For starch availability to increased, the steam-heated grain must be rolled; the thinner the flake, the higher the starch availability. Quality of flakes at the rolls usually is estimated through measuring the air density of flakes with a Winchester cup. A flake weight of 24 pounds per bushel will maximize starch digestion but, to avoid intake reductions possibly associated with very rapid fermentation in the rumen, most commercial flakers target a bushel weight between 28 and 32 pounds per bushel for the hot, wet (20 to 23% moisture) flakes. Flake weight usually is measured hourly during flaking. Flake weight can be altered by adjusting the steaming time and hydraulic pressure on the rolls. In addition, samples of flakes usually are sent to an analytical lab where starch availability is appraised by incubating flakes with starch digesting enzymes or by measuring the amount of gas released during incubation with yeast. Because the analytical results become available long after the grain has been fed, they provide only a retrospective snapshot. More immediate estimates of starch availability have been devised through incubation with enzymes or NIR scans of flakes. As flake density and the temperature of flakes dropping from rolls appear correlated and gelatinization and protein denaturation both are functions of moisture content and temperature, monitoring temperature of flakes also might prove useful as an index of flake quality.

Flake removal and storage

Following flaking, the flakes usually drop into a drag line are or pulled away for temporary storage with an airlift. When flaked, waxy grain may adhere to the hot flaking rolls and complicate operations. Flakes may be fed hot or cooled, but because fresh flakes will contain more than 20% moisture, they can mold within a few days unless dried. Cooling and storage of dried flakes does not reduce their feeding value. During winter months, wet flakes can be stored longer. Hence, for small operations with infrequent flake delivery from a mill, drying of flakes is preferable. As discussed earlier, flakes held warm may retrograde and this will decrease starch availability measured in a laboratory, but whether this decreases their feeding value is uncertain. When flaked, variability among batches of grain and grain hybrids is obliterated. Thereby, daily or weekly variability in rate and extent of fermentation, evident with rolled or ground grains using grain that varies widely in genetic and environmental background can be avoided. This consistency probably is one of the primary but immeasurable benefits gleaned by livestock feeders that use flaked corn grain.

Investments in flaking grain

The fixed cost for equipment and installation of a boiler, steam chambers, flaking rolls and drivers, and all the grain handling equipment for flaking grain are high. At least one person will be kept busy measuring flake density and adjusting the operation of one or several flakers and daily maintenance. In addition, flaking rolls typically are sharpened annually, and the equipment has limited alternative use. Additional ongoing expenses include the cost for generating steam and electrical cost of turning the rolls. Consequently, the fixed and variable costs can be justified more readily at large feedlots or at feed mills that serve a large number of dairy herds. With a flaker, a large inventory of grain is not needed as is true with HMC grain and work is steady throughout the year. When commercial grain is purchased, the operation need not be adjacent to the site where grain is being grown and harvested. Yet locally produced and stored grain often is preferred to avoid blended grains and the physical and nutritional diversity associated with differences in genetic and environmental background.

High moisture corn

Methods for harvest, processing, storing, and feeding HMC (HMC) have been outlined by Mader and Rust (2006) and Hicks and Lake (2006). Operations that use HMC must be located near the site of grain production. Many corn growers prefer to harvest and deliver grain at 26 to 35% and feedlots often develop contracts for grain production with local grain growers that specify the grain price, discounts, and payment schedules. Feedlots may even specify a group of hybrids that are preferable. Grain ground and ensiled with less than 26% moisture undergoes insufficient fermentation to increase starch availability. Indeed, some studies indicate that grain ensiled with 19 to 26% moisture has a feeding value below either that of dry rolled corn or of wetter corn grain! Water can be added to ensiled grain to increase its moisture content, but the amount of water needed to increase moisture content is immense. For example, 3.4 gallons of water is needed to increase the moisture content of 1 ton of high moisture grain from 25 to 26%; 37 gallons of water is needed to increase the moisture content of dry corn from 15% to 26%!

Grain delivery

The length of the harvest window when grain moisture remains between 26 and 35% for most hybrids is only about 15 days. This means that a large amount of grain must be received, processed, and ensiled within a very short time period. To reimburse grain growers, each incoming truckload of grain must be weighed and sampled for moisture content. Price is usually discounted for moisture content similar to grain delivered to an elevator. Often, growers are allowed to receive delayed payment for their grain into the future based on Chicago Board of Trade grain price. Feedlots in turn can sell (though they cannot readily deliver) the ensiled grain on the futures market so that interest is not being paid on their investment in grain.

Ensiling high moisture corn

The shorter the time interval from harvest to packing, the lower the yeast and mold count of the HMC. Though yeasts and molds are aerobic and will not grow in packed silage, HMC that has a high yeast and mold count when it is ensiled will be unstable later when the HMC removed from storage and exposed to air and will heat. Delivered grain usually is processed through large roller mills or tub grinders and samples of processed grain will be checked to avoid whole grain and reduce the prevalence of fine particles. As mentioned earlier, rolling may be preferable to grinding to avoid fine particles, but fine particles are less prevalent when the corn being ground contains more moisture. Additional moisture, often carrying some microbial additive to aid fermentation, commonly is sprayed onto the grain after it is ground or rolled. Grain will be pushed up the exposed slope of the pit with pack tractors, packed into cement-lined bunkers with these tractors, and covered each day with plastic film held in place with bags or split tires. The width of the bunker silo should be proportional to the rate of grain removal to minimize the surface area of grain exposed when it is being removed from storage and fed. A narrow, tall face helps to reduce the amount of stored grain exposed to air and avoid aerobic deterioration. Upright silos and plastic bags (e.g., AgBags) also can be used for ensiling HMC using the appropriate grinding and packing equipment but cost per ton of silage stored usually is much greater than with bunker or pit silos. With any silo system, rapid filling with processed grain, grinding and packing to exclude air, and reducing or preventing air penetration during and exposure after fermentation is ideal. Holes in plastic bags from insects or animals must be promptly sealed to avoid spoilage.

Gas is released during the first several days following ensiling and pH continues to drop over several weeks ideally to 4.5 or below. Lactic and acetic acid and, especially with drier corn, ethanol accumulate during storage that help stabilize the product. But in contrast to corn silage, HMC continues to change during months of storage; solubility of protein in water and starch availability both will increase over many months. These changes occur faster during the first month than thereafter, but changes continue. Two factors markedly increase ruminal degradation of HMC: initial moisture content and duration of storage. This increased fermentation rate makes it hazardous for animal health to switch diets abruptly from HMC that has been stored for only a short period of time to HMC residues that remain from the previous year or from a very dry to a much wetter HMC.

Removal from storage

Fermented grain usually is removed from a pit or trench silo with a front-end loader though smaller loaders can be used for HMC stored in plastic tubes. The amount of grain on the silo face or in piles should be kept to a minimum to reduce loss of nutrients. Drier grain often appears light yellow and white when removed from storage whereas grain with higher moisture content often is tan to reddish or gray in color. This darkening appears to be carmelization, not browning (formation of indigestible Maillard products). Browning would complex protein with reducing sugars reducing the digestibility of protein, but no reduction in protein solubility or digestibility is apparent with darkened HMC. Although the drier brightly colored HMC that resembles ground dry corn may appear preferable to the human eye, it usually has a lower feeding value than darker colored, less appealing, more extensively fermented HMC.

Reconstituted corn grain

Reconstituted corn grain is dry rolled grain to which water is added to a level similar to that found in HMC that is allowed to ferment for at least 30 days. Feeding value of reconstituted grain appears greater than for dry grain but slightly less than HMC of similar moisture content. This may be due to the greater maturity of grain that is fully dry rather than harvested with some moisture still present. This gain in available energy from reconstituting dry grain is partially counterbalanced by the 1 to 5% loss of dry matter and energy during the fermentation process. Nevertheless, as with the flaking process, starch digestibility is greater than for dry processed grain, an inventory of grain for many months is not required as with HMC, and grain to be used for reconstitution can be marketed commercially, unlike fermented grains.

Quality control – Does my herd have any Problem with Starch Digestion?

Two factors are of primary concern when feeding processed grains to ruminants. These are 1) minimizing day-to-day fluctuations in rate of ruminal digestion that cause metabolic disorders and 2) obtaining maximum digestibility of nutrients and energy from the grain.

To reduce the fluctuation in ruminal digestion, cattle feeders or feed callers must minimize the variability of diet through frequent and regular delivery of a properly formulated and fully mixed ration containing grain that is always processed in a consistent manner by the individuals who manage flakers or HMC preservation and retrieval. Day-to-day and meal-to-meal variation must be low for grain fed as flaked (typically appraised by test weight) or HMC (minimized by consistency of the stored product in particle size and moisture content as well as proper silo face maintenance and prompt feeding of uniform, fresh, mixed product). Product consistency is particularly important when diets contain a high amount of processed grain. One advantage from feeding multiple types or forms of grain is to dilute the impact of variation within a single ingredient on the characteristics of the total mixed diet.

The primary goal of grain processing is to increase nutrient digestibility, particularly of starch. Although many methods to predict the starch digestibility of a grain sample have been devised, the animal is the best and final arbiter for starch digestion. Undigested starch provides no energy for growth or lactation. Because all undigested starch is found in feces, concentration of starch in feces is a convenient and reliable index of starch digestion and the efficacy that diet components diet were "adequately" processed. Relationships of starch digestibility to fecal starch (percent of dry matter) for steers (Figure 4) and lactating cows (Figure 5).

Figure 4. Relationship of total tract starch digestion to concentration of starch in fecal dry matter by steers in digestion trials.

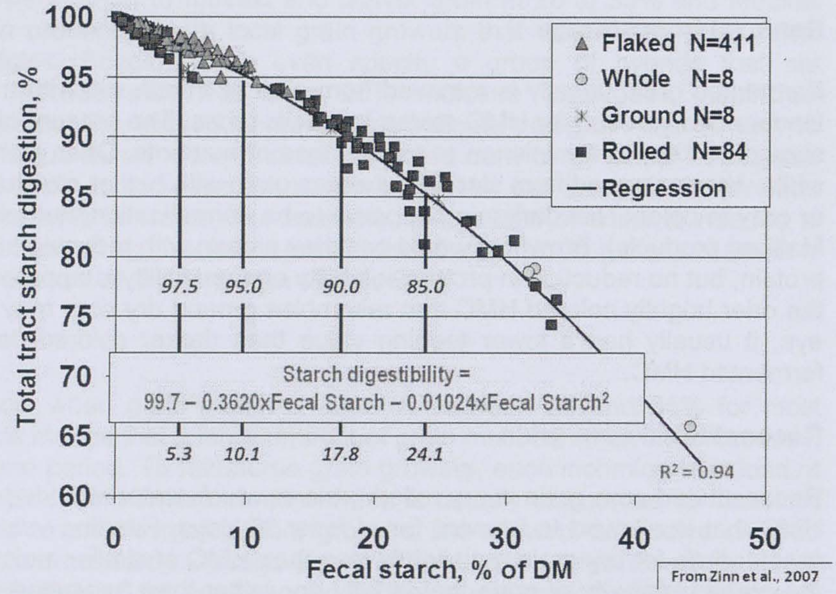
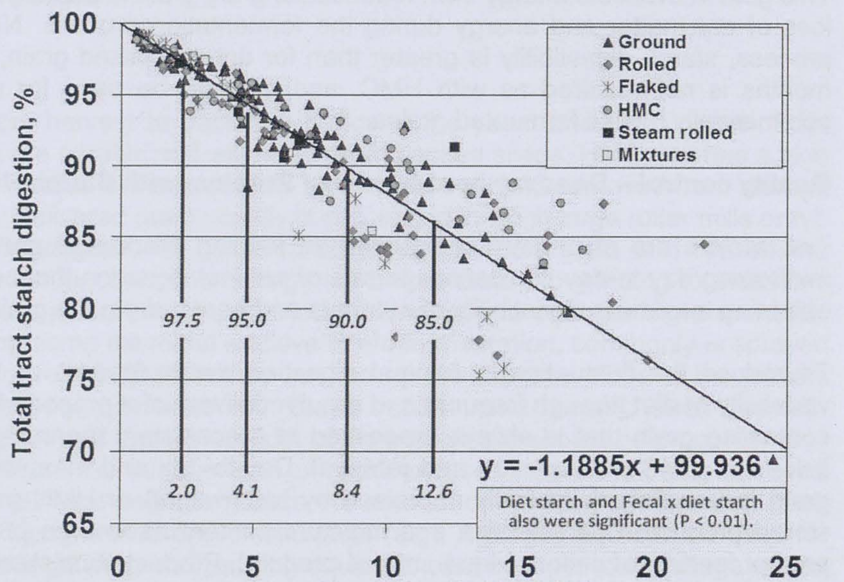


Figure 5. Relationship of total tract starch digestion to concentration of starch in fecal dry matter from lactating cows in digestion trials.



Based on these graphs, grain and silage processing should be considered "adequate" if starch digestibility exceeds 95 to 97% so that concentration of starch in feces is less than 5% of fecal dry matter. Fecal samples, readily assayed at most commercial labs ($19 - $35), should be a representative composite from multiple cattle (ideally 8 or more) that have had consistent intakes of the same diet for more than one week. If the starch concentration is above 5% of fecal dry matter (some say 3% for lactating cows), one or more of the components that contribute starch to the diet is not being well digested. Whether this is the grain or the silage is uncertain. Specific tests for corn silage (kernel processing score), for flakes (density), and HMC (particle size, moisture content) can help detect the culprit. Potential corrective actions include more extensive processing of grain using the current system (finer grind or roll for dry corn; lower flake weight for flaked grain; greater kernel processing for silage or HMC) or switching to another roughage source or level or to a different grain processing method. Any corrective action should not be abrupt but only gradual in order to avoid metabolic disorders. With corn silage or HMC, corrective action (regrinding; addition of water for further fermentation?) may prove expensive and infeasible until the next harvest season. But simply knowing whether starch digestibility is adequate or inadequate can help a livestock producer or consultant to easily determine whether or not the whole issue of grain or silage processing or starch digestibility is having an adverse economic impact and thereby worthy of further attention at a specific feedlot or dairy operation.

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