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Effects of Grain Processing with Focus on Grinding and Steam-Flaking on Dairy Cow Performance

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Abstract

Milk production and milk components are of prime economic importance for dairy farmers. Although milk production depends largely on numerous dietary nutrients, energy and protein are most critical. Feed grains containing starch such as corn, barley, wheat, and sorghum as a primary source of energy are commonly fed to beef and dairy cattle to improve meat or milk productions. Feed grain needs to be processed prior to feed cattle to increase accessibility of the endosperm by microbial population in the rumen and the host enzyme in the intestine. Grain processing is done by the application of various combinations of heat, moisture, time and mechanical actions. This article outlines the effect of grain processing method and degree of processing on rate and extent of grain digestion in the digestive tract of cattle, and consequently on lactation performance and cattle health. Methods of grinding, rolling and steam flaking are particularly discussed on their advantages and disadvantages. The optimal degree of processing can achieve a balance between maximizing the extent and controlling the rate of starch digestion in the rumen to maximize utilization and avoid digestive and metabolic disturbances. A recent developed precision processing technique has been highlighted and discussed as well.

Keywords: grain, processing, grinding, steam-flaking, dairy cow

1. Introduction

It is well known that the diet fed to dairy cows is an important lever by which milk yield and milk composition could be modified. Although milk production is affected by numerous dietary nutrients, energy and protein are most critical. Feed grains containing starch such as corn, wheat,

barley, and sorghum, as a primary source of energy, are commonly fed to livestock to improve meat or milk productions [1]. Improving starch utilization may improve lactation performance in cows and reduce feed costs, especially when grain price is high [2]. Whole grain with an intact pericarp is largely or entirely resistant to digestion by ruminants because whole kernels are resistant to bacterial and host enzyme accessing to endosperm of grain kernel in the rumen and in the intestine, respectively [3, 4]. Therefore, cereal grains require processing to break the protective seed coat, and the fibrous hull in the case of barley and oats, and to improve grain digestibility [5]. Grain can be processed by the application of various combinations of heat, moisture, time, and mechanical action. Nonthermal processes (roller and hammer mill) and thermal processes (roasting, popping, micronizing, autoclaving, steam-flaking, steam pelleting, expanding, extruding, and toasting) could be used to manipulate rate of degradation and hence ruminal availability [6, 7]. The extent and rate of ruminal digestion of grain can be manipulated through processing [8]. The quality of processed grain can be affected by the application of various combinations of heat, moisture, time, and mechanical action [9]. These processing treatments alter kernel structure, thereby enhancing the release of starch granules from the protein matrix and disrupting their order during gelatinization; this, in turn, increases the accessibility of starch to microbes in the rumen and increases the susceptibility to enzyme activity [10]. Thus, grain processing can be a useful tool for optimizing lactating dairy cow production by synchronizing energy and protein to improve rumen microbial protein production. Steam-flaking is a more extensive processing system than dry- or steam-rolling [11]. Steam-flaking has been shown to increase the digestibility of starch by cattle fed corn- or sorghum grain-based diets over whole, ground, or dry-rolled grain [7]. In sorghum, steam-flaking has been found to increase ruminal starch digestion, as compared with dry-rolling or grinding [12]. Consistent increases in ruminal starch digestion have also been observed for steam-flaked corn, as compared with ground or dry-rolled corn [13]. Malcolm and Kiesling [14] reported that steam-flaking of barley tended to increase *in situ* rumen dry matter degradation. These experiments have shown that steam-flaking increases the amount of starch fermented in the rumen and, also, enhances the intestinal digestibility of starch that escape the rumen degradation. Few studies have investigated the effects of steam-flaked barley (SFB) on its digestibility in the rumen and in the total digestive tract of lactating dairy cows. Increasing the extent of grain processing enhances ruminal starch digestion of grain [8]. Additionally, grinding is a conventional processing method used in grain processing for feeding dairy cattle in some countries like Iran because of its low cost, but ground barley is often dusty, thereby potentially reducing feed intake. This response is usually influenced by either the extent of processing or flake density [13]. The objective of this chapter was to discuss the effects of grain processing methods with emphasizes on grinding and steam-flaking and on grain digestibility and lactation performance of dairy cows.

2. Starch in cereal grains

Cereal grains are rich in starch ranging from 40% in oats up to 80% of dry matter in rice, with the variation in starch content dependent on variety, climatic conditions, and agronomic practices [15]. Starch is synthesized into a form of rough spherical granules and, within each feed grain starch granule, multiple concentric semicrystalline and amorphous shells are present [1].

Feed grain starch consists of amylose and amylopectin, as two major components [1, 5], which are present in different proportions in the starch granule of feed grains [1]. Cereal starches are typically composed of 25–28% amylose and 72–75% amylopectin. There are also waxy cultivars with very high amylopectin concentration (up to 100%) and high amylase (up to 70% amylose) cultivars [5]. Starch of waxy barley varieties may be less digestible than normal barley due to the differences in chemical composition and starch structure. Starch granules isolated from different feed grains and other starch sources reveal characteristic morphologies, varying in shape [16], in molecular size [17], and in specific surface structure and porosity [18]. Also, it has been recognized that cultivars or varieties in feed grains vary in granule size distribution, suggesting a significant genetic control [19]. Other components of feed grains, including lipids, proteins, and minerals, are also associated with starch granules. Lipids and proteins are the most abundant nonstarch components in feed grains that may affect physical state and enzyme susceptibility of starch in livestock [20].

3. Role of grain processing in starch digestion

Whole grains with an intact pericarp are largely or entirely resistant to digestion by ruminants because whole kernels are resistant to bacterial attachment in the rumen [3, 4]. Unlike sheep, adult cattles have a limited capacity to masticate cereal grains; hence, it is essential to break the pericarp of the seed either through chemical or physical treatments [21]. In feed grains, germ and endosperm are surrounded by the pericarp, which is largely resistant to microbial attachment [22]. Starch granules from corn grain are surrounded by a protein matrix in the endosperm [23], which influences digestion by microorganisms [24]. Feed grain endosperm encapsulated by protein matrix acts as a physical barrier to protect from enzymatic hydrolysis [25]. It has been shown that this protein matrix by blocking the absorption sites or by influencing enzyme binding may reduce the surface availability of starch to host enzyme and ruminal bacteria [25]. In addition, the results of several studies have shown that hydrophobic properties of grain protein matrix, associated with type and location of proteins, could be responsible for the differences in starch digestion between rapidly digested grains such as wheat, barley, and rice, and slowly digested grains such as maize and sorghum [2, 24]. Processing is necessary for feed grains to break the protective seed coat [3, 5] especially for the grains such as maize and sorghum [11], and the fibrous hull in case of barley and oats, to improve their digestibility in the digestive tract of animals [5]. Feed grain processing by grinding, rolling, pelleting, steam-rolling, or steam-flaking breaks down the recalcitrant barriers such as the hull, pericarp, and protein matrix and allows microbial and host enzyme accessing to the starch within endosperm cells.

4. Impact of grain processing

Grain processing methods could be divided into two groups: (1) nonthermal processes such as roller and hammer mill and (2) thermal processes, which include dry processing (roasting, popping, and micronizing) and wet processing (autoclaving, steam-flaking, steam-pelleting, expanding, extruding, and toasting) [26]. Heat processing, however, has been associated with

increased efficiency of fermentative utilization by altering the protein matrix of the endosperm and the starch structure, thus allowing a better utilization by microbial enzymatic digestion [21]. Increasing the starch availability is the primary goal of grain processing. In addition, processing may destroy mycotoxins and improve mixing characteristics to improve bunk management and thereby enhance animal performance [27]. The processes reduce the particle size of the grain, increasing the surface area available for microbial attachment and colonization; combined, these actions increase the rate and extent of starch digestion [22]. Starch gelatinization, a process in which disaggregated amylose and amylopectin chains in a gelatinized starch paste reassociate to form more ordered structures, and dextrination, formation of dextrans (fragments of amylose and amylopectin molecules formed by heating dry starch in the presence of some moisture, acids, or salts) during processing of grains [28], improve accessibility of enzymes to the starch granules. It, in turn, may shift the site of digestion of protein and starch from the rumen to the intestine [6, 7], and consequently, it results in an improved supply of amino acids and glucose to animal metabolism [29]. Elevated glucose absorption represents one mechanism by which increased intestinal starch digestion might increase milk yield [30]. Increased net energy density of cereals is also beneficial because high-yield dairy cows often are unable to consume sufficient energy during early lactation to meet the requirements.

5. Grain starch digestion in digestive tract of dairy cows

Ruminants do not produce appreciable quantities of salivary amylase, and therefore, starch digestion in ruminants is initiated after ingestion and mastication of feed [1]. Dairy cattle consume large amounts of starch (20–40% of diet DM) as a way to increase energy consumption in support of high milk production [31]. The optimum starch content of diets for lactating dairy cows is not well defined, but 24–26% starch (dry matter basis) has been suggested [32]. Total tract starch digestibility of dairy cows is highly variable and has a range of 70–100% [33]. Quantitatively, most of the starch digestion in ruminants [2] occurs in the rumen (55–85%) and the small intestine (15–25%) with indigestible starch fractions ranging from 0 to 20% of starch intake [2, 34]. The rate and extent of starch digestion in the rumen are determined by interrelations among several factors, including level of feed intake, source of dietary starch, diet composition, grain processing, chemical alterations (fermentation, gelatinization), grain passage rate, and degree of adaptation of rumen bacteria to dietary starch [35]. Digestion of starch in the rumen is facilitated symbiotically by ruminal bacteria with amylolytic capacity [35]. Attachment of bacteria to starch containing feed particles is a key step in bacterial fermentation of starch in the rumen [1]. Although ruminal protozoa play a role in ruminal starch digestion through ingesting and digesting starch granules, eliminating protozoa by rumen defaunation can actually increase rate and extent of ruminal starch digestion [36], which suggests that bacterial fermentation alone is sufficient in starch digestion in the rumen. In general, ruminal starch digestion can vary substantially, ranging from 40 to 80% in lactating dairy cows [2, 33]. Compared to beef cattle, the extent of ruminal starch digestion from maize grain is often lower for lactating dairy cows [34]. The high levels of feed intake, rapid rates of passage and minimal mastication of grain particles by lactating dairy cows are thought to be responsible for

the lower ruminal starch digestion [33, 34]. Approximately 50–90% of the postruminal flow of starch is digested in the small intestine [1, 3] by enzymatic hydrolysis of starch that provides energy in the form of glucose to the animal. The passage rate through the small intestine, surface exposure, and grain endosperm properties can alter the output of enzymatic starch hydrolysis in the small intestine [37]. In the large intestine, around 30–60% of the starch escaping ruminal digestion and enzymatic hydrolysis can be digested via hind gut bacterial fermentation [6] that is symbiotically providing energy in the form of volatile fatty acid.

6. Factors affecting grain starch digestion

The kinetics of starch digestion in livestock animals depend largely on two major factors: (1) the inherent starch architecture and related physicochemical properties and (2) the degree of processing feed grains prior to feeding that vary with methods used such as rolling, pelleting, flaking, extrusion, and expander processing as well as the processing condition setting up of each method [1]. Starches from various sources show different responses to the heat processing conditions. The starch structure can be modified by the application of such processing, thus some native physicochemical starch properties including starch granule morphology, crystallinity, the amylose content, and the type of endosperm are potentially affected [38]. These native physicochemical properties have been recognized to influence the starch digestion of grains [38]. Feed grains fed to livestock are commonly processed through a grinder or a roller prior to feeding, and mechanical processing could be considered as one of the primary and less expensive methods to influence starch digestibility. In commercial sector, various processing equipments with variable screen sizes or mill settings are available to create wide distributions of grain particle sizes and to meet different requirements of animal feeding [39]. The effect of particle size distribution on starch digestion is primarily associated with the available surface area for microbial access and enzymatic hydrolysis [40]. The particle size of grains after processing, even if not directly related to native physiochemical starch properties, also plays a role in determining the relative efficiency of starch digestion within grains [41]. Blasel et al. [41] reported a reduction in the degree of starch access by α -amylase of about 27 g/kg of starch for each 100 mm increase in particle size in ground maize grain. Also, it is reported a reduction in the rate of starch digestion of grounded feed grains through 3.0 mm compared with 0.8 mm opening screen after either 60 or 240 min of in vitro incubation [42]. In addition, it has been observed that there is an inverse square relationship between the enzymatic hydrolysis rates of pancreatic α -amylase and the increasing particle size in milled barley and sorghum grains [43].

6.1. Method of processing

The method of processing grain will depend on the type of grain and the specific feeding and management conditions. Small kernel grain, such as barley and wheat, is usually processed by dry-rolling, steam-rolling, or temper-rolling, while corn grain is often steam-flaked in cattle feeding. Grain can also be treated with chemicals or enzymes to alter the rate and extent of nutrient degradation [26]. Mechanical processing by rolling of the grain cracks or crushes the fibrous hull

and pericarp to enable access of rumen microorganisms and enzymes to the internal endosperm and increases the surface area for attachment [22]. The addition of moisture in steam-rolling and temper-rolling may be advantageous over dry-rolling when the original grain is very dry (<10% moisture), of variable kernel size, rolled more extensively to maximize utilization, and fed with limited amount of forage. Steam-processed grain is exposed to steam at either atmospheric, low, or high pressure to increase grain moisture and temperature before the grain is rolled. Steam-flaking of grain is a more extensive process with longer steam conditioning times and thinner rolled flakes than steam-rolling. The combination of moisture, heat, and rolling causes gelatinization of the starch granules, i.e., swelling of granules as water is absorbed, disruption of the crystalline structure, dissolution of polysaccharides, and diffusion from ruptured granules. Steam-flaking of barley grain increased the *in vitro* amyloglucosidase, catalyzed release of glucose and the rate of starch degradation compared to dry-rolling of the grain [44]. However, the beneficial effects of starch gelatinization for barley may be less than for corn or sorghum grain because barley starch once it becomes accessible readily degraded by ruminal microorganisms [44].

6.2. Degree of processing

The optimal degree of grain processing is aimed at achieving a balance between maximizing the extent and controlling the rate of starch digestion in the rumen to increase utilization and avoid digestive and metabolic disturbances [5]. The degree of grain processing, also called the extent of processing, can significantly affect rate and extent of grain digestibility in the rumen or in the total digestive tract, thus affect feeding value and cattle performance as well as cattle health when the high-grain is fed. Overprocessed grain increases proportion of fine particles, reduces palatability, increases rate of grain digestion in the rumen, hence increases the incidence of digestive disorders such as rumen acidosis, bloat, laminitis, and liver abscesses [5]; whereas underprocessed grain reduces the starch availability for fermentation by rumen microbes [45]. The degree of grain processing has been widely used by cattle nutritionist to manipulate rate and extent of grain digestion in the rumen. Processing index was developed by our laboratory to quantify the degree of processing, and it is currently applied as a routine method by feed mill in grain processing for cattle feeding [4]. The processing index refers to the volume weight (g/L) of barley after processing expressed as a percentage of its volume weight before processing [4]. This index reflects the fact that the more extensively grain is processed (i.e., the higher the degree of processing), the finer the particle will be, hence, the lower the volume weight will be, and consequently, the lower the processing index. Take barley grain as an example; the disadvantages of under- or overprocessing grain on the milk production of dairy cattle were described in a study by Yang et al. [4]; barley grain was steam-rolled to four degrees with processing index of 81, 72, 64, and 55%, and milk production increased quadratically with degree of processing resulting, respectively, in increases of 0, 9.8, 20.3, and 13.3% in milk yield. The reduced milk yield in dairy cows fed coarsely rolled barley grain compared to those fed more extensively processed barley was due to the combined effects of lower feed intake, lower nutrient digestibility, and a slower particle outflow rate from the rumen. We concluded that the optimum extent of barley processing for dairy cows fed diets supplying adequate fiber was a processing index of 64% to maximize milk yield without negatively affecting milk fat percentage.

6.3. Precision processing

Kernel uniformity of grains can vary considerably depending on variety, growing conditions, disease, etc., in particular, grains with lower and higher volume weights are often blended commercially to achieve an intermediate volume weight that increases the market value of the grain [5], but it also increases the variability of kernel size. The poor kernel uniformity can contribute to inconsistent processing especially when the dry-rolling technique is used. We have developed the precision processing method [45–47] that refers to separate fractions of uniform kernel size and then each fraction is processed with an optimum roller setting specific to the kernel size to ensure that all kernels are cracked [46]. For barley grain of variable kernel size and shape, precision processing enables greater control over the extent of processing compared with processing with the conventional one roller setting, particularly when the grain is dry-rolled. Precision processing increased digestibility of crude protein and acid detergent fiber; as a result, organic matter digestibility increased as compared with the conventional processing in a study using beef cattle fed high-grain diet [46]. The barley that was sieved and rolled with settings based on kernel size had increased starch degradability up to 24 h and increased overall rate and effective degradability of starch in the rumen compared to the barley processed as a single roller setting [45]. In a lactation study, dry matter intake, ruminal fermentation, nutrient digestibility, and milk production were not affected by precision processing compared with conventional processing [47]. The differences in the results between the beef and dairy studies are likely due to the differences in the amount of barley grain (67 versus 40%) and forage (10 versus 40%) in the diets.

7. Effects of grain processing on dairy cow performance

7.1. Steam-flaking versus rolling or grinding

Compared with grinding, rolling processing generally reduces starch digestibility in the small intestine and in the total digestive tract of cattle [26]. Larsen et al. [48] in a review reported that reduction in ruminal starch digestion of grains was generally not compensated for by increasing the small intestinal starch digestion but was associated with increases of starch digestion in hindgut. Santos et al. [49] reported that dairy cows fed steam-flaked corn yielded daily 1.5 kg more milk than did cows fed rolled grain, also the yield of milk protein and percentages of lactose and solids that are nonfat increased compared with rolling processing. Similarly, compared with rolling, feeding steam-flaked corn and sorghum increased yields of milk, milk protein, and fat, and protein percentage of milk, which were likely due to the increased total tract digestibility of dry matter, crude protein, starch, and neutral detergent fiber [50]. It suggests that steam-flaking versus rolling improved the feeding value of corn for lactating cows by improving diet acceptability and digestibility of organic matter and increased the estimated net energy for lactation of corn. López-Soto et al. [51] indicated that compared to dry-rolled barley, steam-flaked barley increased ruminal digestion of organic matter and starch of diet, but decreased dry matter intake of lactating dairy cows. Our in

situ experiment [52] showed that ground barley versus steam-flaked barley increased organic matter disappearance (**Figure 1**) and increased the washable fraction (28.3 versus 21.4%), rate of potentially degradable fraction (0.10 versus 0.05 h⁻¹), and effective degradability (60.6 versus 47.6%) of organic matter. In an in vivo study [53] using lactating dairy cows, we observed that the grinding versus steam-flaking barley grain did not affect dry matter intake (23.6 kg/day), digestibility of dry matter in the total digestive tract (71.0%), milk yield (43.4 kg/day), milk components, rumen pH, and molar proportions of acetate, propionate, and butyrate. The lack of difference between grinding and flaking could be due to low grain inclusion rate and minimal difference in the particle size as barley was coarsely ground. In contrast, Eastridge et al. [54] reported that the finely ground corn decreased milk urea nitrogen content compared with coarsely ground corn, suggesting that finely ground corn provided more fermentable starch in the rumen, thus possibly improved bacterial capture of the nitrogen. However, the results on dry matter intake, milk production of lactating dairy cows by feeding steam-flaked corn versus ground corn are inconsistent [55–57]. In another study using lactating dairy cows, we found that grinding versus steam-flaking of barley affected dry matter intake, organic matter digestibility in the total digestive tract, and feed efficiency. The discrepancy among the studies could be due to differences in grain variety, particle size distribution of processed grain, inclusion rate of grain in the diets, which could affect the grain digestibility in the rumen and in the intestine, hence, impact feed intake and milk production of dairy cows (**Figure 2**).

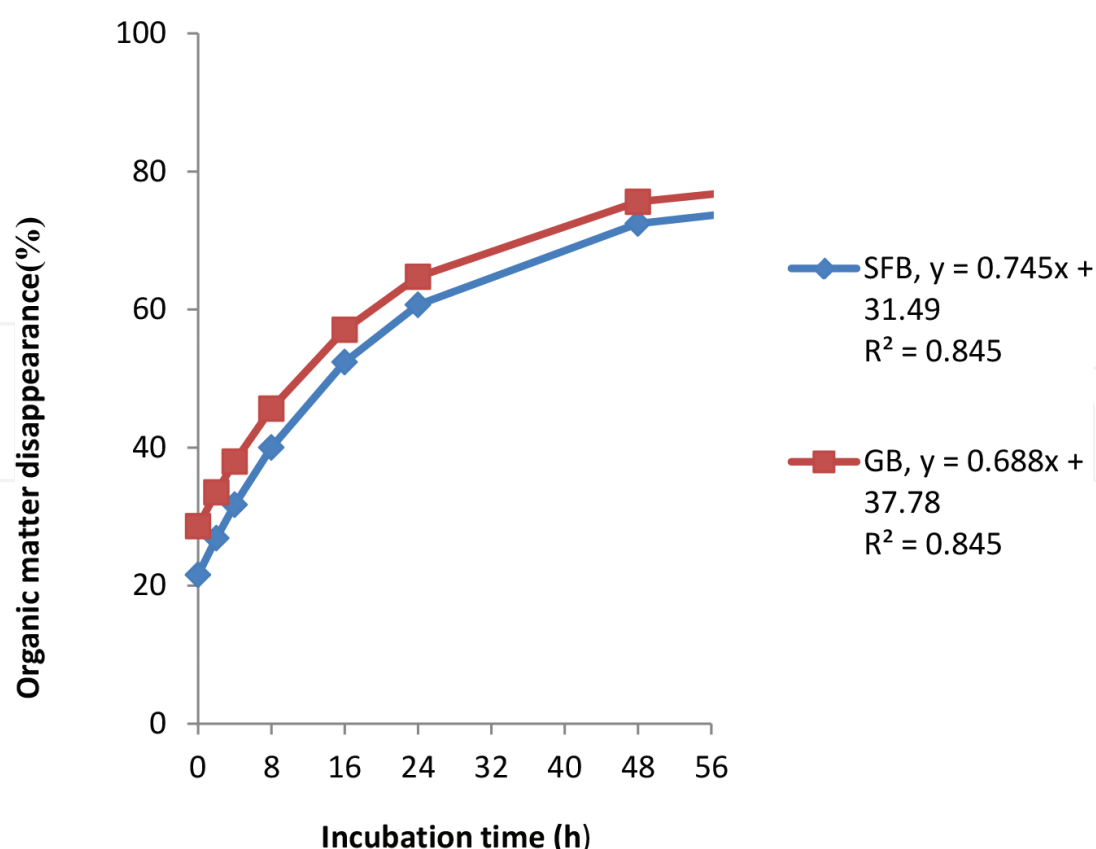


Figure 1. Organic matter disappearance (%) of ground barley (GB) compared to steam-flaked barley (SFB).

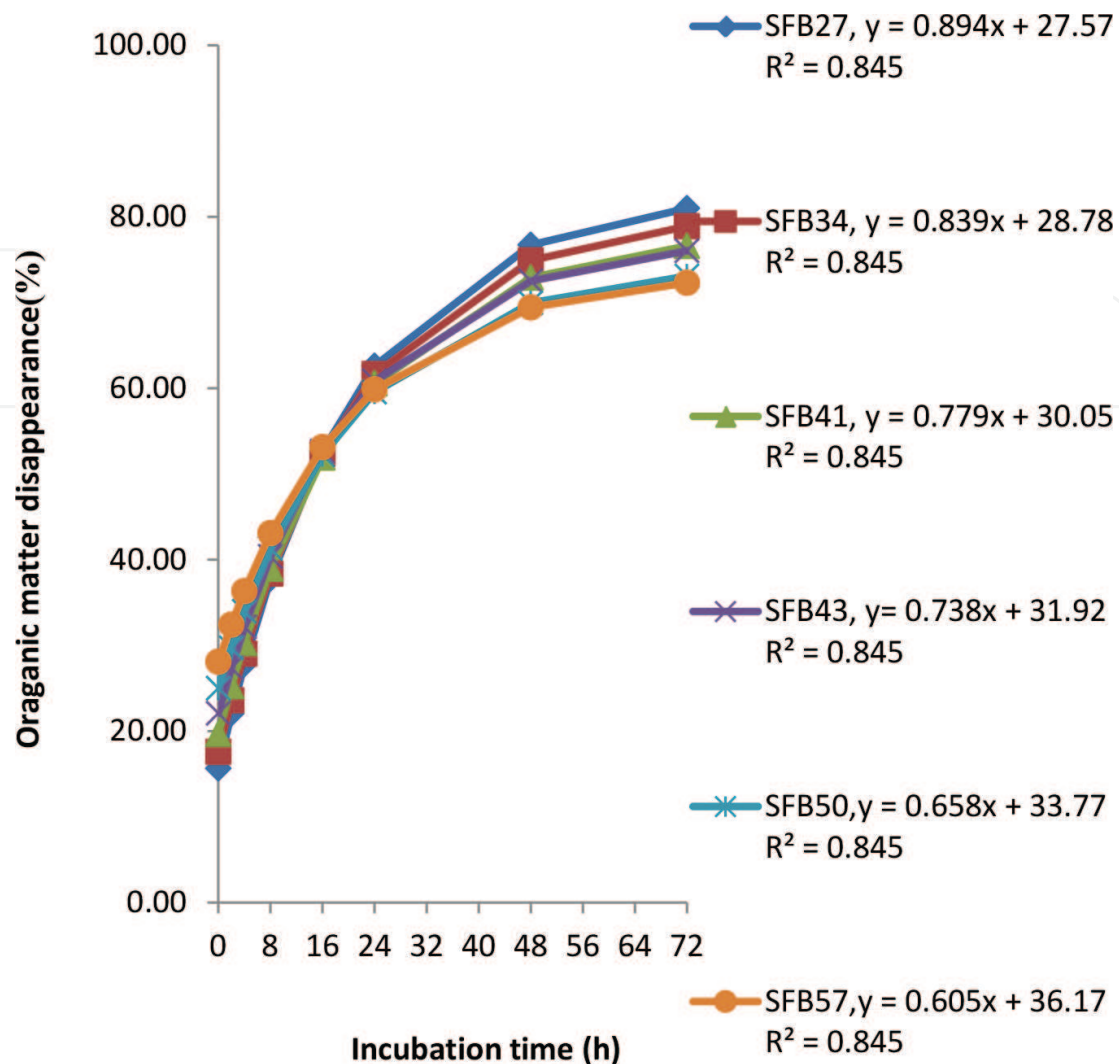


Figure 2. Organic matter disappearance (%) of steam-flaked barley (SFB) with various processing indexes (%).

7.2. Effect of flake density

Flake density of grains affects grain digestibility and cow performance. It was suggested that optimal flake density was between 0.32 and 0.39 kg/L [58]. Zinn and Barajas [59] conducted an experiment to evaluate the influence of flake density on feeding value of a barley-corn blend fed to feedlot cattle, and observed an increase of ruminal digestibility of organic matter, starch, and protein, but a decrease of ruminal nitrogen efficiency with decreasing flake density. We found that decreasing the density of steam flaked barley from 0.30 to 0.26 kg/L increased ruminal digestion of starch and ruminal propionate, but decreased dry matter intake and ruminal protein degradation. These results are expected since decreasing the density of processed barley indicated increased degree of processing, hence increased rumen starch digestibility (**Figure 2**), and consequently, decreased rumen pH (potential rumen acidosis), and decreased dry matter intake. In comparing with corn-based diet, dairy cows fed barley-based diets showed greater dietary energy due to improved ruminal microbial efficiency, greater total tract organic matter digestion, and lower ruminal acetate and methane production. However, dairy cows that were fed barley-based diets had lower ruminal pH, which was exacerbated as flake density decreased.

Results showed 8% improvement in energy value of barley with steam-flaking [51]. Flaking barley too thinly would depress feed intake because of increase in rumen digestion and reduction in rumen pH [51]. Our study also showed that decreasing the density of steam-flaked barley from 390 to 340 to 290 g/L tended to linearly decrease dry matter intake, total solids percentage of milk, and linearly decreased milk urea nitrogen. Finely ground corn increased ruminal propionate concentration and decreased ruminal pH and acetate to propionate ratio, suggesting an increase of grain digestion in the rumen. Increasing density of steam-flaked corn increased total tract digestion of organic matter, neutral detergent fiber, starch, and digestible energy content of diet and increased milk efficiency [60]. It suggests that barley and corn should be processed at different density when it is steam flaked to maximize its digestibility, while to minimize its rumen health problem since barley is more rapidly digestible than corn in the rumen.

8. Conclusion and implication

Improvement and optimization of grain digestion in the rumen and the intestine is an important research focus in cattle nutrition and feeding. Generally, site, extent, and rate of grain starch digestion in the digestive tracts of cattle are influenced by intrinsic and external factors that can be interrelated, hence they are not easily defined. Particle size reduction, starch gelatinization, retrogradation, and dextrination due to grain processing may shift the site of starch digestion from the rumen to the intestine, and thus it results in an improved supply of amino acids and glucose to animal. Steam-flaking grain increases the starch digested both in the rumen and in the intestine; this, in turn, increases the available energy for milk production. Overall, both ground and steam-flaked grains could be fed dairy cows depending on the level of grain in diet, dietary composition, and economic cost of grain processing.

Feeding values differ among grain sources and processing methods used. Although the net energy value of grain usually is increased by more extensive flaking, regardless of grain source or processing, dairy cows can produce milk at similar rates, probably due to reduction in dry matter intake and lower passage rate of flaked grains compared with ground grains. This may support the concept that chemostatic factors generally control intake of low forage diets. For a specific grain and processing method, roughage source and moisture may markedly influence rate of production and net energy value of the grain, probably due to bunk management, diet acceptability, chewing activity, and site and extent of starch digestion.

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