Getting More from Our Conventional Feeds: Barley Grain and Barley Silage

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Take Home Messages

- Shifting site of starch digestion from the rumen to the intestines can be an effective technique to feed high grain diets with corn grain, but this approach may not work for barley grain, and it is more challenging to feed high grain diets containing barley grain.
- Starch content of barley grain may affect the productivity of high-producing dairy cows.
- The extent of processing may affect productivity of dairy cows if poor quality barley grain is used.
- Barley silage varies in fibre digestibility depending on variety and ambient temperature before harvest, and fibre digestibility can affect productivity of lactating dairy cows.

Introduction

According to Dairy NRC (2001), forage neutral detergent fibre (NDF) requirements of dairy cows are related to dietary non-fibre carbohydrate (NFC) content. For example, NRC recommends that cows fed 44% dietary NFC need to have at least 19% forage NDF in the diet. Although this guideline may be commonly accepted in the US and eastern Canada where corn grain is the primary starch source in dairy diets, it is considered as an “aggressive” guideline in western Canada where barley grain is the primary starch source. Indeed, Dairy NRC (2001) pointed out that the recommendation was made with the assumption that dry corn grain is the primary starch source. In addition, barley silage is the primary forage used in western Canada because it is difficult to harvest high quality corn silage consistently due to the lack of heat units. Diet formulation approaches should be different if barley grain and barley silage are used instead of corn grain and corn silage, but it is important to first note the differences in digestive characteristics between corn and barley grain. The objective of this paper is to review research that has evaluated effects of feeding barley grain and barley silage and discuss nutritional management approaches to optimize their utilization in dairy diets.

▪ Differences between Corn Grain and Barley Grain

It is important to understand the differences in morphology between barley and corn grains. The pericarp of barley grain is overlain by a fibrous hull and is extremely resistant to microbial degradation in the rumen; whole unprocessed barley grain is very low in digestibility (Beauchemin et al., 1994). Thus, processing makes the starch more accessible to microbes and increases the rate and extent of starch degradation in the rumen. Contrarily, corn grain does not have extensive fibrous layers, but has a protein matrix made of prolamin protein that protects starch granules in the endosperm from microbial degradation. Starch digestibility is negatively related with prolamin protein content in corn grain (Larson and Hoffman, 2008) while such a relationship is not observed for barley grain (Oba et al., 2010).

A fibrous hull is the primary barrier against starch digestion in barley grain while a protein matrix is the primary barrier in corn grain. This difference affects digestion characteristics of these grains. If barley grain is not digested in the rumen due to insufficient processing, most of the remaining starch is not likely digested in the lower digestive tract. Mammals do not have enzymes to digest fibre, and a fibrous hull is not digested in the small intestine where starch is digested and absorbed as glucose. As such, post-ruminal digestion of starch is not expected to be high for improperly processed barley grain, thus it is important to maximize starch digestion in the rumen for barley grain. If it is not digested in the rumen, it does not likely provide energy to animals and is excreted in feces. Contrarily, as the protein matrix is the primary barrier against starch digestion in corn grain, protein digestion is tied to starch digestion in corn grain. Protein is different from fibre, and can be digested in the abomasum and small intestine. As such, even if starch in corn grain is not digested in the rumen, it has another opportunity to be digested in the lower digestive tract. This allows us to feed more corn grain to dairy cows without increasing the risk of rumen acidosis. Shifting site of starch digestion from the rumen to the small intestine can be an effective nutritional approach to increase dietary starch supply for corn grain, but not for barley grain.

The difference in digestive characteristics between corn and barley is demonstrated in the study of McCarthy et al. (1989). Cows were fed either steam-rolled barley or dry ground corn in high starch diets. Ruminal starch digestibility was 77.1% for cows fed barley grain while it was 49.3% for cows fed corn grain. However, cows fed corn grain extensively digested starch in the lower digestive tract (44.0%), and the total tract starch digestibility was 93.3%, which was slightly lower than that of cows fed barley grain (96.8%). It is noteworthy that cows fed corn grain increased dry matter intake (DMI) by 3.1 kg/d, which can be attributed to less starch fermentation and the reduced risk of rumen acidosis. We need to be aware that it is more challenging to feed high grain diets if we use barley grain as the primary starch source in dairy diets.

It is generally accepted that replacing corn grain with barley grain decreases DMI and milk yield due to excess fermentation in the rumen for cows fed barley grain, but effects of grain type on milk production are not always consistent. The discrepancies can be attributed to the differences in the level of dietary grain allocation, dietary starch concentration, and availability of physically effective fiber among studies. For example, as mentioned above, McCarthy et al. (1989) reported 3 kg/d reductions in both DMI and milk yield when corn grain was replaced by barley grain in the diets of lactating dairy cows. In their study, the experimental diets contained steam-rolled barley grain at 49% of dietary DM. Similarly, Silveira et al. (2007) fed high grain diets (39% of dietary DM) with whole crop barley silage as the primary forage, and reported that cows fed barley grain reduced DMI and milk yield. Contrarily, Grings et al. (1992) reported that replacing a mixture of corn grain and beet pulp with barley grain did not affect DMI or milk production. Their experimental diets contained barley grain at 36% of dietary DM, but the dietary forage sources were alfalfa hay (22% of dietary DM) and alfalfa silage (22% of dietary DM). Presumably, the experimental diets used by McCarthy et al. (1989) and Silveira et al. (2007) were far more fermentable compared with Grings et al. (1992). Interactions between fermentability of grains and that of the basal diet need to be considered for optimum utilization of grains.

Barley grain is not fed to lactating dairy cows as a sole feedstuff, but as a part of total mixed ration (TMR) with the other feed ingredients. Therefore, the impacts of grain quality on milk production need to be discussed with considerations of how barley grain is used in the diet. Feeding highly fermentable grains often decreases feed intake and milk production especially when they are fed in high grain diets, but may not negatively affect productivity of dairy cows when they are fed in low grain diets. Rather, if diets are formulated properly, feeding highly fermentable grains would enhance milk production by increasing energy intake and metabolizable protein supply. If a high forage diet is fed to animals, the major factor that limits maximum milk production may be energy availability. In this situation, animals will likely benefit from barley grain with greater starch content and energy availability. However, if a low forage diet is fed to animals, they may already be experiencing subclinical rumen acidosis, and feeding highly fermentable grains in this dietary setting likely decreases milk fat content, feed intake and even milk production. The optimum utilization of barley grain is affected by how it is incorporated in dairy diets.

▪ Impacts of Variation among Barley Grain

A significant variation exists in the chemical composition of barley grain. The diversity in barley grain quality among different sources is due to geographical, environmental and genetic variations as well as their interactions. The ranges of variations in crude protein (CP) and starch concentration of 60 barley varieties grown in variable environments are 10.8 to 16.2% and 48.3 to 62.5%, respectively (Khorasani et al., 2000). These data are consistent with previous findings. Ovenell-Roy et al. (1998) reported that barley grain varied from 17 to 32% in NDF concentration, and from 45.9 to 62.8% in starch concentration among 12 samples.

We evaluated feeding values of two barley grain lots, Dillon and Xena varieties, at the University of Alberta (Silveira et al., 2007; Table 1). These variety lots were selected because of the distinctive differences in their physical and chemical characteristics, and because they represented the typical range of variation for barley grain. We formulated diets that contained steam-rolled barley grain, either Dillon or Xena, at 39% of dietary DM, and fed these to dairy cows in peak lactation. Cows fed Xena increased milk yield by 2.3 kg/d, and tended to decrease milk fat concentration by 0.24% units compared with cows fed Dillon. Expected diet fermentability in the rumen was greater for cows fed steam-rolled Xena as Xena had greater starch content and in vitro starch digestibility. Cows fed Xena maintained similar DMI as cows fed Dillon, and consequently increased energy intake and milk production. This study demonstrated that selection of barley grain lots can affect productivity of lactating dairy cows. However, our research data need to be interpreted with caution as we compared a single lot of Xena with a single lot of Dillon, and it is not known whether the lots of barley grains used in this study are representative of each variety. Thus, we cannot conclude that Xena is always the better variety for lactating dairy cows because the growing environment and its interaction with genetics greatly affect the physical and chemical characteristics of barley grains.

Schlau et al. (2013) conducted a similar study evaluating two lots of barley grain that differed in bulk density and starch content, and reported that milk production was not affected by treatment. One of the possible reasons explaining the discrepancy between the two studies is the difference in milk production level; Silveira et al. (2007) used cows in peak lactation producing more than 40 kg/d milk at the beginning of the study while Schlau et al. (2013) used late-lactating cows producing less than 30 kg/d milk. Maximum milk production of cows used in the study of Silveira et al. (2007) might have been limited by energy intake, and as such, increasing energy intake by feeding Xena vs. Dillon barley might have increased milk production. However, cows used in the study of Schlau et al. (2013) might have consumed sufficient energy regardless of barley grain used in their diets, and this might explain why the barley grain treatment did not affect milk production. We need to note that animals respond differently to grains varying in nutrient composition.

Table 1. Effect of barley grain differing in starch content on productivity of lactating dairy cows

	Silveira et al., 2007			Schlau et al., 2013		
	Dillon	Xena	*P* value	Light	Heavy	*P* value
Barley grain						
Bulk density, lb/bushel	47.8	58.5		41.0	53.3	
Starch, %DM	50.0	58.7		49.6	64.3	
NDF, %DM	27.0	19.0		29.3	18.6	
CP, %DM	10.1	12.6		13.0	13.6	
Production						
DMI, kg/d	21.4	21.8	0.35	24.0	23.9	0.30
Milk yield, kg/d	36.2	38.5	< 0.05	28.8	28.3	0.37
Milk fat, %	3.47	3.23	0.08	3.90	3.94	0.60
Milk protein, %	2.89	3.08	< 0.01	3.45	3.45	0.90

■ Impacts of Extent of Grain Processing

Whole unprocessed barley grain is very low in digestibility, and processing makes the starch more accessible to microbes and increases the rate and extent of starch degradation in the rumen (Beauchemin et al., 1994). Barley grain is generally processed by grinding, dry-rolling, steam-rolling, or temper-rolling, and effects of these processing methods on productivity of ruminants have been reviewed (Dehghan-Banadaky et al., 2007). Although processing improves the utilization of nutrients in barley grain, extensive processing increases ruminal starch degradation, which often decreases feed intake in ruminants (Allen, 2000). Extensive dry-rolling often generates fine particles and results in rapid ruminal fermentation, and may decrease the productivity of ruminants (Wang et al., 2003). Therefore, the objective of barley grain processing should be to optimize the digestibility rather than maximizing the digestibility.

The Processing Index (PI) is a parameter indicating the extent of processing, and is expressed as the volume weight of barley grain after processing as a percentage of its volume weight before processing. Yang et al. (2000) fed barley grain, steam-rolled to coarse, medium, medium-flat and flat (PI = 81.0, 72.5, 64.0, and 55.5%, respectively), at 42.5% of dietary DM to lactating dairy cows. Total tract starch digestibility and milk yield increased linearly as the PI decreased from 81.0 to 64.0% (Table 2). However, further reduction in the PI from 64.0 to 55.5% did not increase total tract starch digestibility but decreased DMI and milk yield. It is important to identify the optimum extent of processing because maximizing fermentation in the rumen does not necessarily maximize milk yield. Yang et al. (2000) concluded that the optimum PI is 64% for barley grains fed to lactating dairy cows as it maximized milk yield.

Table 2. Productivity and total tract starch digestibility of cows fed steam-rolled barley grain varying in processing index (Yang et al., 2000)

	Coarse (81.0%)*	Medium (72.5%)	M-flat (64.0%)	Flat (55.5%)	SE	*P* value	
						Linear	Quadratic
DMI, kg/d	18.7	21.4	21.7	20.1	0.6	0.12	< 0.01
Milk yield, kg/d	25.6	28.1	30.8	29.0	0.4	< 0.01	< 0.01
Milk fat, %	3.93	3.89	3.78	3.90	0.06	0.50	0.25
Milk protein, %	3.15	3.30	3.29	3.34	0.02	< 0.01	< 0.05
Total tract starch digestibility, %	78.0	84.1	93.6	92.9	1.7	< 0.01	0.10

* Processing index (PI) = volume weight of barley grain after processing expressed as a percentage of its volume weight before processing

However, the optimum extent of processing is expected to differ depending on the quality of barley grain prior to processing. Barley grain used by Yang et al (2000) was 44.4 lb/bushel and 26.5% NDF, which is different from barley grains typically used in the feed industry. In a similar study conducted at the University of Alberta (McGregor et al., 2007), barley grain (53.1 lb/bushel and 16.8% NDF) was steam-rolled to either 82.5 or 68.7% PI, and fed to lactating dairy cows at 38.4% of dietary DM. Dry matter intake and milk yield were not affected by the extent of processing in this study (Table 3) although Yang et al. (2000) reported approximately 5 kg/d increase in milk yield for the equivalent comparison of PI (81.0 vs. 64.0%). These discrepancies might be attributed to the differences in physical and chemical characteristics of barley grain prior to processing. Barley grain with low NDF content, such as the one used in the study of McGregor et al. (2007) might require less processing with little marginal benefits from processing further, while highly-fibrous barley grain, such as the one used by Yang et al. (2000), may need more extensive processing to optimize rumen fermentation and digestibility.

Table 3. Productivity of cows fed steam-rolled barley grain varying in processing index (McGregor et al., 2007)

	Coarse (82.5%)*	Fine (68.7%)	SE	*P* value
DMI, kg/d	20.4	20.8	0.3	0.44
Milk yield, kg/d	29.2	29.5	0.8	0.38
Milk fat, %	3.61	3.66	0.07	0.24
Milk protein, %	3.18	3.21	0.03	0.09

* Processing index (PI) = volume weight of barley grain after processing expressed as a percentage of its volume weight before processing

▪ Getting More from Barley Silage

Many forage quality parameters affect diet formulation approaches and feeding costs, and in vitro fibre digestibility (IVFD) is one of the quality parameters that has consistent effects on productivity of dairy cows. According to the statistical analysis of treatment means from experiments reported in the Journal of Dairy Science, a one-unit increase in *in vitro* or *in situ* digestibility of NDF is associated with a 0.17 and 0.25 kg/d increase in DMI and 4% fat-corrected milk yield, respectively (Oba and Allen, 1999b). Effects of forage IVFD on milk production have been extensively studied for corn silage, and corn silage hybrids for enhanced IVFD are developed and commercially available in the US. Contrarily, impacts of IVFD on animal performance had not been extensively investigated for barley silage. However, a recent multi-year project conducted at the Field Crop Development Centre in Lacombe showed that there was a consistent difference in IVFD between whole-plant barley cultivars (i.e., Falcon and Tyto; 6-row, semi dwarf, hulless barley; Table 4), and identified genetic markers relating to IVFD.

Table 4. Chemical composition and 30-h in vitro fibre digestibility (IVFD) of Falcon and Tyto whole plant barley silage grown at common environment (2005 – 2011)

	Falcon (n = 11)	Tyto (n = 11)	SE	*P* value
CP, %	12.3	11.6	0.41	0.28
Starch, %	20.8	19.1	1.00	0.22
NDF, %	40.9	45.1	0.77	< 0.01
ADF, %	24.4	27.6	0.59	< 0.01
30-h IVFD, %NDF	52.9	49.0	0.85	< 0.01

We conducted a study at the University of Alberta to compare diets containing Falcon or Tyto barley silage (Table 5). The 30-h IVFD of the Falcon and Tyto barley silage was 61.6% and 57.2%, respectively. In order to formulate diets that were similar in protein and NDF contents, the Falcon-based TMR contained more barley silage (65.6% vs. 60.0% of DM), less steam rolled barley (9.4% vs. 12.9% of DM) and less canola meal (4.6% vs. 6.7% of DM) than the Tyto-based diet. There was no difference between treatments in DMI (28.2 vs. 29.2 kg/d), milk yield (38.5 vs. 38.1 kg/d), milk composition or milk component yield. However, cows consuming the Falcon-based TMR utilized feed more efficiently than did cows consuming the Tyto-based TMR (1.44 vs. 1.32 kg milk / kg DMI). In addition, it should be noted that the diet containing Falcon, without negatively affecting milk production, reduced the feeding costs as it contained less purchased feedstuffs. The IVFD of whole plant barley silage varies among barley varieties, and it can be an important consideration when balancing diets for high-producing lactating cattle.

Table 5. Productivity of lactating dairy cows fed Falcon and Tyto barley silage (Swift et al., 2011)

	Falcon	Tyto	SE	*P*
DMI, kg/d	28.2	29.8	1.7	0.33
Milk yield, kg/d	38.5	38.1	1.0	0.41
Milk fat, %	3.56	3.55	0.11	0.86
Milk protein, %	3.03	3.06	0.05	0.27
Feed efficiency, milk yield / DMI	1.44	1.32	0.08	0.03

The IVFD of barley silage is also affected by the growing environment, especially ambient temperature before harvest. We conducted a study to evaluate the effect of planting date on IVFD of whole-crop barley and its effects on productivity of lactating dairy cows. In this study, we planted barley either on May 5 (BM) or June 7 (BJ) to alter the growing environment, and harvested at the similar physiological stage (i.e., late dough stage) on July 26 or August 25, respectively, for BM and BJ (Table 6). The BJ had greater 30-h IVFD (61.2 vs. 51.9%) possibly because BJ was exposed to the lower daily mean temperature from heading to harvest (14.3 vs. 15.9ºC). Although DMI and milk yield were not affected by barley silage treatment (averaged 20.2 and 27.2 kg/d, respectively), cows fed BJ had greater total tract dry matter digestibility (68.9 vs. 66.1%) and tended to increase body weight gain (864 vs. 504 g/d) compared with those fed BM, indicating that more energy was available from the barley silage with enhanced IVFD. Nonetheless, the lack of significant responses could have been attributed to the low-energy demands for cows used in this experiment; ruminal physical fill might not have limited DMI.

Table 6. Chemical composition and 30-h in vitro fibre digestibility (IVFD) of whole plant barley planted in May or June, and their effects on productivity of lactating dairy cows (Chow et al., 2008)

	May Barley	June Barley	SE	*P*
Planted	May 5	June 7	…	…
Harvested	July 26	August 25	…	…
Barley silage				
CP, %	8.7	12.4	0.08	< 0.01
Starch, %	25.9	23.0	1.11	0.21
NDF, %	51.3	52.5	0.66	0.34
30-h IVFD, %NDF	51.9	61.2	0.52	< 0.01
Production				
DMI, kg/d	20.4	19.9	0.55	0.17
Milk yield, kg/d	27.2	27.1	1.11	0.84
Milk fat, %	3.77	3.72	0.11	0.50
Milk protein, %	3.45	3.48	0.06	0.19
BW change, g/d	504	864	129	0.06

Although further research is still needed to confirm the values of IVFD in barley silage, particularly for high-producing dairy cows, IVFD data still provides very useful information for nutritional management of dairy herds. For instance IVFD is a powerful tool to rank forages by their quality. Positive effects of enhanced IVFD are greater for cows yielding more milk possibly because their maximum feed intake is limited by physical fill in the rumen to a greater extent compared with lower-yielding cows (Oba and Allen, 1999a). Lower producing cows had little response in DMI and milk yield to the forage with greater IVFD, and it is likely because their feed intake is not limited by physical fill of the diets. Thus, forages with greater IVFD should be allocated to higher yielding cows that will benefit the most. If a farm can feed different lots of forage to 2 or more groups of lactating cows, there is an opportunity to increase the benefit of enhanced IVFD by feeding the forage with greater IVFD only to cows that will benefit the most.

The IVFD data may also affect how diets are formulated. When grain price increases, feeding costs can be reduced by increasing the forage content in the diet. However, as forage NDF is filling and often limits feed intake, forages with greater IVFD will allow more forage to be fed without compromising milk production. In a previous experiment (Oba and Allen, 2000), cows fed a corn silage with enhanced IVFD in a high forage diet, without supplemental grain, produced as much milk as cows fed a corn silage with lower IVFD in a diet which contained corn grain at 30% of dietary DM (33.7 vs. 33.5 kg/d). Identification of forages with greater IVFD will allow more forage to be fed and decrease feeding costs without reductions in milk yield when grain is costly. This creates significant flexibility in diet formulation especially because grain costs relative to forages are highly variable.

Analysis of forages for IVFD is also an important troubleshooting tool. For instance, milk yield sometimes decreases when switching from old silage to new crop silage. Although many possible factors may be related to a reduction in milk production when switching to new crop forage, if the new forage crop is significantly lower in IVFD, physical fill might be a dominant factor limiting feed intake, decreasing milk yield. On the other hand, if the new forage crop is significantly greater in IVFD than the current forage that you have been feeding, the new diet may depress milk fat content unless the diet is adjusted. If you open the silo a couple of weeks before you start feeding to high producing cows, and feed it to heifers, you will have sufficient time to take a representative sample, analyze it for IVFD, and make necessary adjustments in diet formulation. Assessment of new forages for IVFD to compare with the forage from a previous year can prevent a potential problem before it occurs.

■ Conclusion

Some diet formulation recommendations of Dairy NRC (2001) cannot be accepted in dairy diets based on barley grain and barley silage, and we need to be aware of differences in digestion characteristics between corn and barley grains. Shifting the site of starch digestion from the rumen to the intestines can be an effective technique to increase dietary grain allocation with corn grain, but this approach may not work for barley grain. It is more challenging to feed high grain diets with barley grain. Starch content of barley grain affects the productivity of high-producing dairy cows, and the extent of processing may also affect productivity of dairy cows if low quality barley grain is used. Whole crop barley silage varies in IVFD, and it is affected by cultivar and ambient temperature before harvest. The IVFD can be an important quality parameter of forages affecting productivity of lactating dairy cows.

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