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# EFFECTS OF BARLEY PROCESSING AND VARIETY ON RUMINAL DISAPPEARANCE IN FEEDLOT CATTLE

KELSEY VIRGINIA SHAMPOE
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Reviewed and approved* by the following:

Tara Felix
Assistant Professor and Beef Extension Specialist
Thesis Supervisor

William Staniar
Associate Professor of Equine Science
Honors Adviser

* Signatures are on file in the Schreyer Honors College.

## ABSTRACT

Although common in animal feeds, traditional varieties of barley have a tough outer hull that necessitates processing and increases cost. Using hulless varieties increases digestibility of barley in nonruminant diets; however, data on the efficacy of these varieties as feed for cattle are lacking. Therefore, objectives of this study were to compare ruminal disappearance of dry matter (DM), neutral detergent fiber (NDF), and starch in traditional whole barley (WB), rolled barley (RB), and whole hulless barley (HB). Ruminally fistulated steers (n=8) were used. Each treatment, WB, RB, and HB, was ground in a Wiley mill with no screen to mimic the mastication that would occur if the animals were fed naturally. Then, samples were weighed into Dacron bags and incubated in the rumen for 3, 6, 12, 24, 48, and 72 hours. Residual contents were analyzed to determine in situ disappearance of DM, NDF, and starch. Data were analyzed using MIXED procedures of SAS (9.4 SAS Inst., Cary, NC) with repeated measures. Steer was the experimental unit and significance was declared at $P<0.05$. Dry matter disappearance (DMD) was greatest ($P<0.05$) for RB at all time points and did not differ ($P>0.05$) between HB and WB between hours 3 to 12. However, HB had greater ($P<0.05$) DMD from 24 to72 hours than WB. The NDF disappearance (NDFD) was greatest ($P<0.05$) for HB at all time points, while RB and WB were comparable. Despite a 50% increase in starch degradation of HB compared to WB at hour 3, the 2 varieties did not differ ($P>0.05$) until hour 72, likely because of steer variation. In situ NDFD was increased in HB when compared to RB and WB; however, DMD and starch disappearance were not markedly different.

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# Chapter 1

# Review of Literature

## 1.1 Barley Production and Utilization

Cereal grains are grasses that are primarily grown and cultivated for their edible grain components: endosperm, germ, and bran. Worldwide, cereal grains provide more energy than any other crop. Barley is one such cereal grain typically grown in temperate climates for a variety of uses. Among cereal grains, barley is currently the fourth most widely used, with applications in products used for both humans and animals (Nikkhah, 2012). For humans, barley is used in certain breads, soups, health products, and particularly in malted alcoholic beverage products, such as beer. For animals, barley has primarily been fed as an energy source (Newman and Newman, 2008).

Given the wide variety of uses for barley, it is no surprise that the grain is grown and harvested worldwide. The USDA indicates that global barley production in the 2015-2016 season was roughly 149.6 million tons and roughly 145.9 million tons for the 2016-2017 season. The majority of production comes from European Union countries, who contributed roughly 60 million tons in both of these recorded seasons. Beyond these countries, Russia, Ukraine, Australia, and Canada are all significant contributors to barley production. The United States is also a key producer, harvesting roughly 4.3 million tons of barley in the 2016-2017 season (USDA, 2018). Major contributors in the United States include Montana and North Dakota, each producing over 20,000,000 bushels in 2017, and Idaho, which produced over 40,000,000 bushels in 2017 (USDA, 2017).

Barley's worldwide use may be partially attributed to its hardy agronomic properties. Although barley is not grown as widely, in a geographic sense, as other grains, it does adapt well to certain growing conditions that make it advantageous in certain areas. Barley, as a result of a fibrous outer hull, is more resistant to desiccation and more adaptable to saline soils than many other cereal grains, allowing it to thrive in more temperate climates that other grains may not. These adaptations have made it a suitable crop to be grown in areas that may otherwise struggle with more delicate crops: the Great Lakes region, the northern plains and mountain states, and the northwest coast in the United States; and throughout much of Canada as well (Boyles et al., 2001). In addition, barley has a relatively short growing period of approximately 62 days, which makes it an attractive option for producers seeking to increase per acre productivity by double cropping (Cheeke, 2005). Barley is also relatively low in cost compared to other grains, with estimated savings of $0.75 to $1.00 per bushel over corn on an energy value basis (Kniffen, N.d.). These characteristics make it economically advantageous both as a crop and as a potential feed source. Despite its agronomic benefits, however, barley's fibrous outer hull hinders its use as an animal feed.

Barley's hull necessitates processing before the grain may be included in animal diets. When processing is applied appropriately, it can improve nutrient availability within a given barley variety (Newman and Newman, 2008). Many nutritionists have tolerated this processing necessity because of barley's agronomic regional growth and the fact that barley as an animal feed offers a number of potential benefits, particularly its high protein and starch concentrations.

**1.2 Nutrient Composition of Barley**

Barley has a number of characteristics that make it advantageous as an animal feed. First and foremost, barley grain is an excellent source of protein, containing roughly 30% more protein than corn and a similar protein concentration to wheat and oats (Nikkhah, 2012). Barley grain also contains greater concentrations of essential amino acids, including methionine, lysine, cysteine, and tryptophan, than corn. These increased concentrations in barley may reduce, or entirely eliminate, the need for costly supplementation of proteins that are common in corn-feeding operations (Boyles et al., 2001).

The most abundant nutrient in barley, however, is carbohydrates. Of these carbohydrates, starch provides the majority of the energy derived from the barley grain. Starch contributes to roughly 60% of the barley grain's dry matter content (Newman and Newman, 2008). This high starch concentration contributes to rapid fermentation and degradation. When introduced and maintained properly, this starch may be beneficial, particularly in ruminants, to improve both energy and nitrogen utilization (Nikkhah, 2012). Barley contains less net energy overall than corn, but this deficiency can be overcome by feeding at a slightly greater percentage of body weight (Newman and Newman, 2008).

Traditional barley also contains more fiber than other commonly used animal feed ingredients, such as sorghum or corn. Fiber is a necessary part of many animal diets. In nonruminants, a large proportion of fiber is indigestible, so its inclusion in the ration is necessary to promote gastrointestinal mobility and to aid in excretion (Berrocoso et al., 2015). In ruminants, some types of fiber can be digested by the rumen microbes, while others remain indigestible. The underlying goal of including fiber in the ruminant ration, however, is to stimulate rumination and support a microbial population necessary to properly digest feed. Those fibers able to contribute to this ideal environment are termed effective fibers (Parish, 2007). Unfortunately, in cattle, the fiber found in barley is not generally considered an effective fiber source, as it is rapidly degraded and fails to stimulate rumination (Nikkhah, 2012).

Micronutrients, like vitamins and minerals, must also be carefully considered if barley grain is used as an animal feed. In particular, barley lacks carotene. The carotenoids are precursors to Vitamin A synthesis in animals (Bauernfeind, 1972). Thus, barley feeding generally necessitates supplementation with Vitamin A. Barley also lacks sufficient levels of calcium, but corn and sorghum share this characteristic as well; all require supplementation. In addition, barley lacks zinc and selenium, which may need to be replaced with a mineral salt (Boyles et al., 2001). Despite these well studied nutrient comparisons, the exact composition of barley remains variable depending on a number of environmental and growing conditions. Nutrient concentrations can be affected by growing factors, such as geographical location, year, soil quality, cultivar, and pesticide use (Brown et al., 1987). Protein content, in particular, has been shown to vary with soil fertility and nitrogen levels, and this protein content can have effects, both positive and negative, on net energy content of the barley grain (Boyles et al., 2001). Processing can also greatly affect the nutrient availability within a barley feed.

### 1.3 Barley Processing

Despite its many benefits and various uses, barley remains of limited use in its natural state due to its tough, outer hull, which is poorly masticated and relatively indigestible by ruminants and nonruminants alike. The hull prevents access to the nutrient-dense endosperm of the whole barley grain, thus limiting nutrient availability. Because of this barrier, whole barley generally necessitates processing in order to be of use in virtually all animal feeds. It is estimated that without processing, only 60% of the nutrients contained in barley are available (Boyles et al., 2001). There are many different processing techniques, each with its own benefits and drawbacks, including dry-rolling, tempering, steam-flaking, grinding, roasting, and pelleting, among others (Newman and Newman, 2008). Dry-rolling, in particular, has proven advantageous in barley processing, and it is estimated that this technique alone can improve the digestibility of the grain by as much as 15% to 30% (Lardner and Penner, 2015).

Although these processes differ in implementation, the ultimate goals remain the same. Primarily, processing is needed to yield a small particle size. Reduced particle size allows intestinal microbes to better access the nutrient-rich endosperm for degradation. Further, reduction in particle size allows for more thorough distribution in mixed rations and improved acceptability of fibrous feeds (Boyles et al., 2001).

As expected, processing can be costly. Unfortunately, because of the varying regional availability and use of barley, specific estimates for the costs associated with its processing are not reliable. However, these estimates are available for similar processes in corn and can be used to make inferences about costs of barley processing. Dry-rolling has historically been the least expensive option, with a processing cost of $0.03 per bushel. Fine grinding poses a similar expense, with a processing cost of $0.05 per bushel. Steam-flaking is by far the most expensive option, with a processing cost of $0.20 per bushel (Peters, 2006). Again, although these costs are estimated in relation to corn processing, they can be used to illustrate the expected costs of similar processing methods for barley.

In human and consumer products, processing may be avoidable for some uses, but, in feed type barley for animals, processing has historically been an inescapable and cumbersome cost to the producer. However, there is an emerging variety of naturally hulless barley. Studies investigating hulless barley's ability to reduce the need for processing, thereby reducing cost and improving economic value of barley feeding where implemented, are ongoing.

## 1.4 Barley Varieties and Hulless Barley

Barley can be categorized in a number of very general ways, such as 2-row or 6-row, and malt quality or feed quality. Malt quality barley and feed quality barley refer to the intended use of the barley grain. Malt barley is typically low in protein and is appropriate for brewing and distilling of alcoholic beverages. Feed barley, on the other hand, is generally higher in protein, but most often is included in the diet as an energy source (Cheeke, 2005). Row categorization refers to the number of spikelets present on the grass (2 or 6). Two-row barley has a plump kernel and soft endosperm, and it is generally higher in starch and more suitable for dry growing conditions. Beyond these differences, however, 2-row and 6-row types generally have similar nutrient concentrations within an individual variety.

Barley varieties can also be differentiated based on relative chemical compositions, such as low or high β-glucan, or characteristics, such as waxy or normal starch (Bhatty, 1999). One such variety, which differs in physical characteristics as well as nutrient composition, is known as hulless barley.

As implied by the name, hulless barley is a domesticated variety of barley developed to mature without the tough, fibrinous coat that is characteristic of traditional barley. In comparison to traditional hulled barley, the hulless variety has roughly 3% greater crude protein on a dry matter basis, as well as greater concentrations of limiting amino acids such as lysine and threonine

(Vasanthan and Meale, 2015). In addition, hulless barley has roughly 3% greater starch content than hulled barley, as well as greater concentrations of soluble β-glucans, which can favorably influence both nitrogen and energy release when included in rations at appropriate levels. These increased nutrient concentrations are presumed to be a direct result of the reduced hull, which, when present in whole barley, imposes a dilution effect. Without the barrier of the hull, there is greater availability of the nutrients present (Bhatty, 1999).

### 1.5 Feeding Hulless Barley to Animals

The lack of the tough outer hull makes hulless barley an attractive consideration for animal feeds. Without the hull, there has been some speculation that the feeding value of hulless barley may be greater than the feeding value of traditional varieties, and, perhaps, more similar to the feeding value of corn grain (Wu et al., 2006; Yang, 2017).

Mitchall et al. (1976) began comparative studies in swine by examining the differences among traditional barley, hulless barley, and wheat. Two separate feed trials were conducted in 8 weanling pigs between 22 and 50 kg. The study found that, when fed at comparable levels, there were no differences in feed intake or feed efficiency among any of the grains. Pigs had an average daily gain (ADG) of 0.62 kg per day regardless of treatment diet. Energy digestibility was greatest in the pigs fed hulless barley, despite the fact that traditional, hulled barley had greater protein digestibility than hulless (Mitchall et al., 1976). Nonetheless, in swine diets, corn is generally the more widely utilized energy substrate.

To investigate the hypothesis that hulless barley varieties may be comparable to corn, Wu et al. (2000) tested hulless barley as an alternative energy source to corn for growing-finishing pigs.

Because barley has a slightly lower energy content than corn, the barley diets included slightly higher grain concentrations to allow for more direct comparison of energy availability. The study reported that, when fed diets including 73% corn or 83% hulless barley during the grower period, pigs on the hulless barley diet exhibited an ADG roughly 6% greater than pigs fed corn. Later, when fed diets including 77% corn or 88% hulless barley during the finisher period, pigs exhibited identical ADG, at approximately 0.9 kg. Furthermore, because daily feed intake did not differ between pigs fed barley or corn throughout the trial, feed-to-gain ratio was 4% lower during the finisher period and 5% lower overall for pigs fed barley as compared to corn. These results suggest that barley, when fed at a slightly higher proportion of the diet to account for energy differences, improves feed efficiency and may warrant consideration as a potential energy source substitute to corn in swine diets (Wu et al., 2000).

Studies surrounding the use of hulless barley in dairy cattle exist, but their primary focus is on lactation and productivity effects (Yang et al., 2017; Yang et al., 2018). A study was conducted with 24 lactating Holstein cows assigned to 1 of 4 diets, each formulated at 20% grain on a dry matter basis. The grain portion of each of these diets consisted of 100% corn, 67% and 33% hulless barley, 33% corn and 67% hulless barley, or 100% hulless barley (Yang et al., 2017). The authors reported the greatest DM intake for cows fed the diets with 100% corn grain and 100% barley grain, and there were no differences in milk yield or milk protein content between these treatments. Although milk fat concentration was elevated in cows fed the 67% hulless barley diet, reasons for the elevation were not well understood. Because past research has suggested improvements in nutrient availability (Bhatty, 1999), Yang et al. (2017) also investigated nutrient digestibility among the 4 diets but reported that total tract digestibility of dry matter, crude protein, and neutral detergent fiber did not differ among feeds and that starch digestibility was only minimally different among feeds. These results suggested hulless barley was a suitable replacement for corn at 20% inclusion in lactating dairy cow diets.

In a subsequent study, Yang et al. (2018) investigated the effects of whole, hulled barley versus hulless barley fed in diets containing either 65% or 45% forage to lactating dairy cattle. This study was conducted on 24 lactating Holstein cows assigned to 1 of 4 experimental diets: 45% forage with either hulled or hulless barley as the sole grain source, or 65% forage with either hulled or hulless barley as the sole grain source. Results indicated that neither the type of barley nor the forage concentration in the diet affected milk yield. Further, barley type did not have any effect on milk fat or milk protein concentration. The study concluded that although the level of forage inclusion in the diet may have significant effects, feeding hulless barley as a grain source did not cause any difference in milk composition when compared to hulled barley.

Because hulless barley is an emerging concept and not yet well implemented, there is a limited amount of information available on its efficacy for feedlot cattle. One study in feedlot cattle compared traditional whole and hulless varieties (Zinn et al., 1996), both processed by means of dry-rolling and steam flaking. Results showed that total tract digestibility of organic matter, ADF, starch, and overall energy were greater in the hulless barley than the traditional, hulled barley. Total net energy (NE) was also increased in diets containing the hulless barley compared to the traditional, hulled barley, suggesting a potential for greater feed efficiency should this energy prove more available as suspected. However, ruminal pH was reduced and ruminal propionate concentrations were increased as a result of feeding the hulless barley, thus raising concerns about ruminal acidosis and bloat because of rapid starch degradation (Zinn et al., 1996).

## 1.6 Summary

Although less commonly grown and fed to animals than corn, barley grain offers a number of advantages as a feed source. Barley has greater protein, essential amino acid, and fiber concentrations than corn. In addition, processed traditional barley has been shown, in both nonruminants and ruminants, to yield a similar, if not greater, average daily gain when fed comparably to corn (Mitchall et al., 1976; Zinn, 1996). Unfortunately, traditional whole barley grains are covered by an indigestible outer hull and require processing to achieve their benefits in feed. However, there is an emerging variety of hulless barley that possesses many qualities that suggest promise as a feed source in ruminants. This variety is more readily adaptable to temperate climates and has a shorter growing period than other grains, thus making it an economically beneficial choice. Further, this barley variety has high levels of starch and β-glucans to provide energy, and its inherent lack of a tough hull allows these nutrients to be more readily available than in traditional, whole barley (Bhatty, 1999). However, there is a dearth of information making direct comparisons between hulless barley, whole barley, and processed barley in feedlot cattle. The purpose of this study was to compare ruminal disappearance of dry matter, fiber, and starch in traditional whole barley, rolled barley, and whole hulless barley. It was hypothesized that hulless barley would have a greater extent of ruminal disappearance of dry matter, fiber, and starch than whole barley and would be more comparable to rolled barley.

# Chapter 2

# Effects of Barley Processing and Variety on Ruminal Disappearance in Feedlot Cattle

## 2.1 Introduction

Feed processing costs are a significant consideration for producers. Although many feed processing techniques improve nutrient availability of feeds, and, thus, improve animal performance, processing applications impose extra costs. These costs may increase the price of the animal product to the consumer or, alternatively, reduce the net profit to the producer. This consideration and trade-off is particularly true in regards to barley. Whole barley is plagued by a tough, fibrous outer hull that is indigestible in both nonruminants and ruminants alike. In order for animals to efficiently use the nutrients in barley, the barley must be processed (Newman and Newman, 2008). The cost of processing barley has led agronomists and producers to seek alternative varieties.

One such alternative that may be both economically and nutritionally promising is a naturally hulless barley variety. This variety lacks the tough pericarp of traditional whole barley and contains greater concentrations of protein, limiting amino acids, and starch than hulled barley (Bhatty, 1999). The absence of the hull also allows greater availability of these nutrients. Although the efficacy of hulless barley in cattle operations has yet to be seen, there are promising results in nonruminants. For example, one study in swine, fed grower-finisher rations, has shown that hulless barley varieties, in comparison to corn, offer similar or superior average daily gain, with a decreased feed-to-gain ratio and an improved feed efficiency (Wu et al., 2000). A separate study in swine investigated a more direct comparison of traditional barley to hulless barley and reported that although there were no differences in average daily gain or feed efficiency, there was an increase in energy digestibility for the hulless barley over the whole barley (Mitchall et al., 1976). A singular trial in feedlot cattle reported that, with processing kept constant across varieties, hulless barley offers not only greater net energy but also greater total tract digestibility of organic matter, acid detergent fiber (ADF), and starch than traditional, whole barley (Zinn et al., 1996). However, additional trials investigating the efficacy of hulless barley in beef cattle diets are lacking.

## 2.2 Materials and Methods

All animal procedures were approved by the Pennsylvania State University Institutional Animal Care and Use Committee (IACUC protocol #47255)

Three barley treatments were tested to determine the difference in in situ disappearance of dry matter (DM), starch, and neutral detergent fiber (NDF) concentrations, The 3 treatments were: 1) whole, traditional barley (WB), 2) processed (rolled), traditional barley (RB), and 3) whole, hulless barley (HB).

Initial samples of each treatment were analyzed for DM (method 934.01: AOAC, 1988), starch (Hall, 2009), and NDF and ADF content (ADF; method 5 and 6, respectively; Ankom200 Fiber Analyzer, Ankom Technology, Macedon, NY).

Samples of each of the 3 barley treatments, WB, RB, and HB, were ground twice through a Wiley mill with no screen (Thomas Scientific, Swedesboro, NJ) to mimic cattle mastication and reduce particle size for degradation (Dr. Robbi Pritchard, personal communication). Eight fistulated steers were fed a corn-based diet for ad libitum intake. Dacron bags were labeled according to sample ID, animal, and collection time and weighed. Barley grain (15 ± 0.2 g) was weighed into Dacron bags with 4 replicate bags per treatment at each time point (3, 6, 12, 24, 48, and 72 hours of incubation). Bags were tied shut with nylon string, grouped by hour within steer, and placed in larger mesh sacs. Weights were inserted in the mesh sacs, and the mesh sacs were placed directly in the rumen via the cannula of each steer to achieve 72, 48, 24, 12, 6, and 3 hours of incubation and such that all mesh bags were pulled from the rumen simultaneously. After removal from the rumen, all sample bags were immediately placed in cold (~4° C) water. Sample bags were washed 6 times to remove debris or until the rinse water ran clear. Samples were then placed in aluminum pans and dried at 55° C for 3 days, with each pan and its contents rotated every 12 hours for even drying.

After drying, each sample bag and its contents were weighed and recorded. Percent loss was calculated for each sample and samples were composited by animal and hour such that the CV was less than 10%. Combined samples were then ground through a Wiley mill (1 mm screen; Thomas Scientific, Swedesboro, NJ) and analyzed for DM, starch, and NDF concentrations, as previously described. Disappearance of each nutrient was then calculated using the formula:

$$\%\ loss = \left[1 - \left(\frac{ending\ dry\ sample\ wt.}{starting\ dry\ sample\ wt.}\right)\right] * 100$$

## 2.3 Statistical Analysis

Data were analyzed using MIXED procedures of SAS (v. 9.4 SAS Institute Inc., Cary, NC) with repeated measures to determine the effects over time. Steer was the experimental unit, using the model:

$$Y_{jklm} = \mu + c_j + G_k + T_l + (GT)_{kl} + e_{jkl}$$

where $Y_{jklm}$ = response variable; $\mu$ = mean; $c_j$ = random effect of calf (or steer); $G_k$ = fixed effect of grain treatment; $T_l$ = fixed effect of time; $(GT)_{kl}$ = fixed effect of the interaction of grain treatment and time; and $e_{jklm}$ = experimental error. Significance was declared at $P \leq 0.05$.

## 2.4 Results

Dry matter and starch concentrations are similar across the 3 treatments; however, as expected, the fiber concentrations (ADF and NDF) were reduced in the HB when compared to either WB or RB (Table 1).

There was a treatment by hour interaction for DM disappearance (Figure 1). Dry matter disappearance (DMD) was greatest ($P<0.05$) for RB at all measured time points when compared to HB or WB. Dry matter disappearance did not differ ($P<0.05$) between HB and WB for hours 3 to 12. However, from hour 12 to 72, HB had greater ($P<0.05$) DMD than WB, but remained less than RB.

In addition to DMD, there was a treatment by hour interaction for NDF disappearance (Figure 2). However, in this case, NDF disappearance was greatest ($P<0.05$) for HB at all time points. Fiber disappearance for RB and WB remained comparable ($P>0.05$) throughout all time points.

There was also a treatment by hour interaction for starch disappearance (Figure 3). Starch disappearance was greatest (*P*<0.05) in RB at all measured time points. Although starch degradation in HB was more than twice that of WB at hour 3, the 2 feeds did not differ (*P*>0.05) at that time, due to a combination of steer and lab variation. The 2 feeds remained comparable until hour 72, at which point HB had a greater disappearance (*P*<0.05) of starch than WB.

In addition to the interaction of treatment by hour, there was a main effect of treatment on DM, NDF, and starch disappearance (Table 2). Dry matter and starch disappearance were greatest (*P*<0.01) for RB and least for WB; HB was intermediate and different from both RB and WB. However, NDF disappearance was greatest (*P*<0.01) for HB, but did not differ between RB and WB.

All treatments differed by hour (*P*<0.01) as well; however, this finding is not novel as it is an expectation in in situ trials (results not shown).

## 2.5 Discussion

Although there is a dearth of information regarding the use of hulless barley in feedlot cattle, there are a number of nonruminant studies that can be drawn upon. Mitchall et al. (1976) compared traditional whole barley to hulless barley and wheat and found that, when fed at equal concentrations, there were no differences in ADG but that digestible energy (DE) in hulless barley was greater than that of all other tested feeds. The majority of energy obtained from barley feeds results from starch degradation (Nikkhah, 2012). In the present trial, HB contained roughly 7% more initial starch than RB and roughly 9% more initial starch than WB (Table 1). We hypothesized that starch disappearance would be greater from HB than WB, due to the lack of the tough outer hull, and comparable to processed, RB. However, HB had less starch degradation than RB at all time points, and did not differ in comparison to WB until hour 72. One of the reasons for the lack of differentiation between HB and WB starch disappearance in this trial may be due to the artificial mastication used to simulate animal chewing. Both treatments, WB and HB, were run through a Wiley mill with no screen to simulate chewing. While this technique has been employed in the past (Dr. Robbi Pritchard, SDSU; personal communication), it may not be accurately representative of the animal's chewing activity. Therefore, differences may be less exaggerated in the in situ trial performed here than in an in vivo digestibility trial.

In dairy cattle, research on feeding hulless barley remains limited. Yang et al. (2017) fed hulless barley and corn diets at 20% grain on a DM basis to lactating dairy cows and reported no differences in milk yield and milk fat concentrations. A separate study by Yang et al. (2018) reported that feeding hulless barley and hulled barley diets to lactating dairy cows also did not result in differences in milk yield or milk fat concentrations. These studies suggest comparable digestibility among hulless and traditional barley varieties, as they yielded similar performance results when fed. Thus, they are in line with our in situ work suggesting similar DM and starch disappearance between WB and HB.

One of the major differences in the present trial was the increased NDF disappearance of HB when compared to WB and RB. While cattle can and do use NDF as an energy source as well, there is likely not an improvement noted in the dairy trials (Yang et al., 2017; Yang et al., 2018) previously conducted due to the low initial concentrations of NDF in the HB. That is, the differences noted in the present trial for NDF disappearance may not be biologically relevant.

However, challenges exist in making direct comparisons to the present study, as the main objectives in many dairy studies involve milk yield and composition. Nonetheless, there is only one trial that the author is aware of that studied hulless barley fed to beef cattle and, thus, dairy cattle trials are included for completeness of the discussion.

Zinn et al. (1996) investigated the relative value of processed traditional and processed hulless barley feeds. These authors reported that feeding cattle hulless barley resulted in less feed intake but offered similar dietary net energy (NE) compared to traditional barley in beef cattle. In addition, Zinn et al. (1996) reported that ruminal pH was reduced in cattle fed hulless barley compared to cattle fed traditional barley. This may align with the present trial, because although HB and WB starch disappearance did not differ until hour 72, there was a 100% increase in starch disappearance in HB when compared to WB at hour 3. This difference suggests that there is rapid ruminal degradation of starch within the first 3 hours of feeding and likely a greater availability of starch within the HB as compared to the WB. Although not specifically confirmed in the present trial, rapid fermentation of starch in the first 3 hours would be expected to decrease ruminal pH, just as was reported in the Zinn et al. (1996) work, because starch degradation is directly related to acid production in the rumen (Huntington and Richards, 2005). Although the rapidly degraded starch in hulless barley may be beneficial from an energy standpoint, Zinn et al. (1996) suggest that there may be challenges associated with this characteristic in that it has the potential to contribute to rumen acidosis. The results here suggest that RB, which had a greater starch degradation at all time points, contributed to an even more acidic rumen environment than either the HB or WB. In this sense, there may be value in the lesser starch disappearance of HB in comparison to RB.

Furthermore, Zinn et al. (1996) reported that there was greater post ruminal availability and total tract digestibility of organic matter, ADF, and starch in cattle fed hulless barley compared to cattle fed whole barley when both feeds were processed. The present trial reported only ruminal disappearance. There may be further effects in hindgut contributions to digestibility of the whole grains used in the present trail beyond those results obtained from rumen degradation alone. More work in this area is needed to determine the fiber and starch total tract effects of feeding hulless barley.

## 2.6 Conclusion

Hulless barley offers a number of potential benefits as a grain source. In terms of cropping concerns, this variety is more readily adaptable to temperate climates and has a shorter growth period, thus allowing it to thrive in certain areas where other grains may not. In terms of feed efficiency, hulless barley has generally been shown to match or exceed the value of corn in both nonruminant and ruminant diets. However, because there is a lack of prior comparative data on feeding hulless barley versus whole or processed barley, the impetus for pursuit of hulless barley as an alternative to costly processing remains to be seen.

The results collected here indicate that, despite a doubling in starch degradation at hour 3, HB did not differ from WB in regards to either DM or starch disappearance for the majority of measured time points. Rolled barley remained superior to both WB and HB in terms of DM and starch disappearance at all time points. However, HB did have greater NDF disappearance than either RB or WB at all measured time points.

Nonetheless, the results discussed here should not be considered conclusive in isolation. Because this study was conducted in situ, only conclusions about ruminal degradation should be made. There is an assumption in this trial design that ruminal disappearance directly correlates with energy digestion and absorption. However, this is not necessarily true, as cattle have the ability to further digest feeds in both the small and large intestine. Therefore, comparisons of ruminal degradation should be further tested in the context of a full digestibility trial. In this context, it may be possible to analyze the proportion of nutrient excretion in relation to ruminal disappearance and better associate animal growth and performance with nutrient utilization.

# Chapter 3

## Tables and Figures

### 3.1 Tables

**Table 1**. Chemical Analysis of Barley Treatments

| | Barley Treatment | | |
|---|---|---|---|
| | Hulless | Rolled | Whole |
| Analyzed Composition, % DM basis | | | |
| DM[1] | 87.43 | 87.17 | 87.32 |
| NDF[2] | 14.49 | 22.26 | 22.45 |
| ADF[3] | 1.19 | 6.38 | 7.17 |
| Starch | 68.66 | 64.06 | 62.84 |

[1]DM = dry matter

[2]NDF = neutral detergent fiber

**Table 2**. Main Effects of Treatment on DM, NDF, and Starch Disappearance

| | Barley Treatment | | | | *P*-value |
|---|---|---|---|---|---|
| | Hulless | Rolled | Whole | SEM | TRT |
| Disappearance, % DM basis | | | | | |
| DM[1] | 28.77[b] | 55.67[a] | 22.96[c] | 0.4364 | <0.01 |
| NDF[2] | 45.71[a] | 26.45[b] | 25.18[c] | 0.8762 | <0.01 |
| Starch | 34.20[b] | 70.96[a] | 30.46[c] | 1.0294 | <0.01 |

[1]DM = dry matter

[2]NDF = neutral detergent fiber

**3.2 Figures**

**Figure 1.** Effects of Barley Treatment on Dry Matter Disappearance

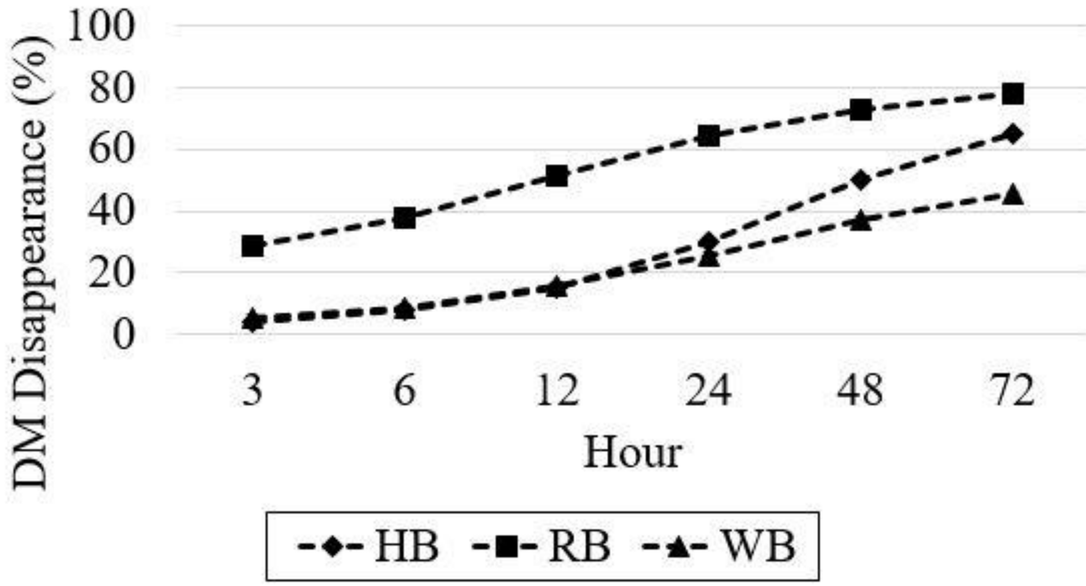


**Figure 1**. Effect of barley treatment on dry matter disappearance from 3 to 72 hours post-ruminal incubation. Where HB = hulless barley, RB = traditional rolled barley, and WB = traditional, whole barley that has not been processed. All treatments were ground through a Wiley mill with no screen prior to ruminal incubation. There was a significant ($P<0.05$) treatment, hour, and treatment by hour interaction for in situ DM disappearance. The error bars reflect the SEM associated with the interaction of treatment by hour (SEM=1.17).

**Figure 2**: Effects of Barley Treatment on NDF Disappearance

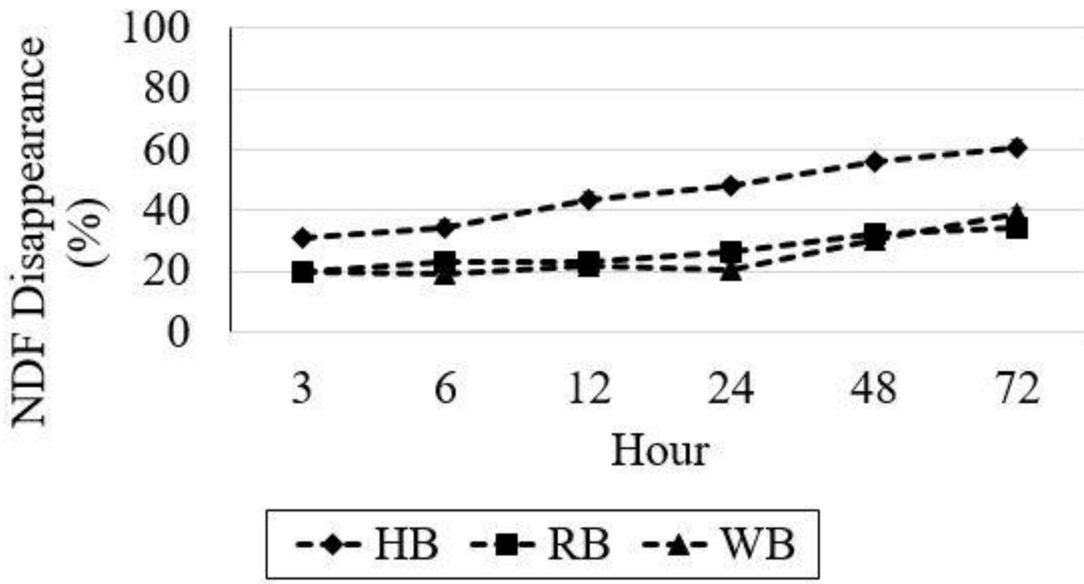


**Figure 2**. Effect of barley treatment on neutral detergent fiber (NDF) disappearance from 3 to 72 hours post-ruminal incubation. Where HB = hulless barley, RB = traditional rolled barley, and WB = traditional, whole barley that has not been processed. All treatments were ground through a Wiley mill with no screen prior to ruminal incubation. There was a significant ($P$<0.05) treatment, hour, and treatment by hour interaction for in situ NDF disappearance. The error bars reflect the SEM associated with the interaction of treatment by hour (SEM=2.22).

**Figure 3**: Effects of Barley Treatment on Starch Disappearance

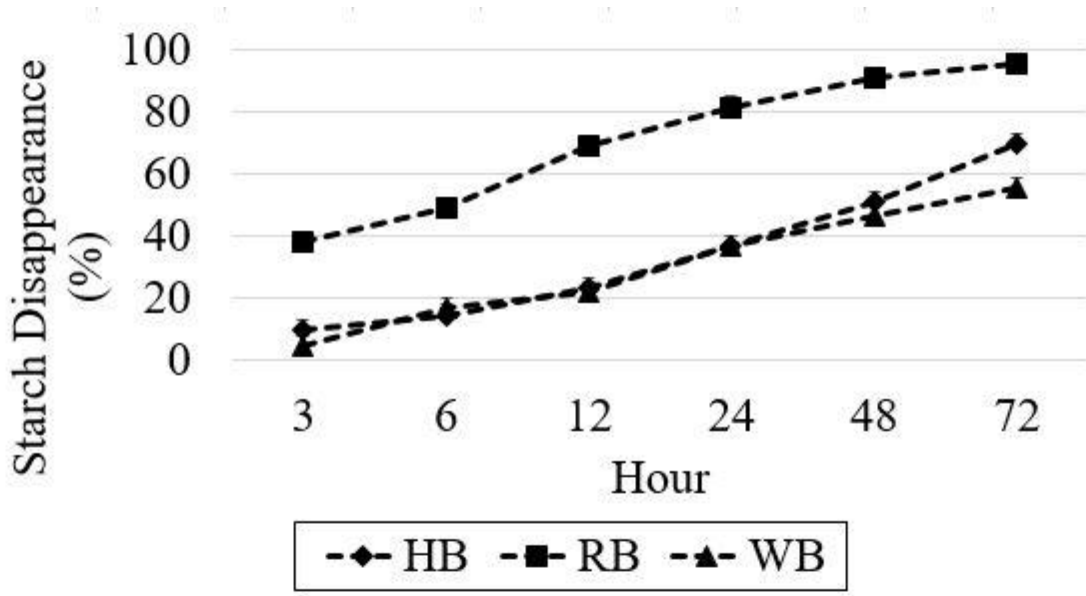


**Figure 3**. Effect of barley treatment on starch disappearance from 3 to 72 hours post-ruminal incubation. Where HB = hulless barley, RB = traditional rolled barley, and WB = traditional, whole barley that has not been processed. All treatments were ground through a Wiley mill with no screen prior to ruminal incubation. There was a significant (*P*<0.05) treatment, hour, and treatment by hour interaction for in situ starch disappearance. The error bars reflect the SEM associated with the interaction of treatment by hour (SEM=3.28).

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# ACADEMIC VITA


**Academic Vita of Kelsey Shampoe**
kps5196@psu.edu


**Education:**

The Pennsylvania State University
Schreyer Honors College
College of Agricultural Sciences

- B.S. in Veterinary and Biomedical Sciences, 2018

**Work Experience:**

**Centre County PAWS**; State College, PA — October 2016 - Present
*Medical Assistant*

- Conducted routine medical care (vaccinations, bloodwork, microchipping, etc.), arranged professional treatments and procedures with local veterinarians, and managed medical inventory for over 100 resident dogs and cats at a non-profit, no-kill animal shelter

**McKean Veterinary Hospital**; McKean, PA — May 2016 - Present
*Veterinary Assistant*

- Aided veterinarians with restraint, sedation, medication, surgery, and behavioral therapy at a privately owned, mixed animal practice

**Awards/Honors:**

- Dean's List, The Pennsylvania State University, 2014-2017
- Dowler Family Scholarship, College of Agricultural Sciences, 2016
- Rosie and Stuart Kahan Scholarship in Pre-Veterinary Sciences, 2016
- Galen Dreibelbis Endowment for Excellence in Agriculture, College of Agricultural Sciences, 2015
- Society of Distinguished Alumni Trustee Scholarship, Schreyer Honors College, 2014
- J. Ronald and Patricia L. Gatehouse Scholarship, Schreyer Honors College, 2014

**Extracurriculars:**

- Penn State Pre-Vet Club, treasurer — 2016 - Present
- Schreyer Honors College Orientation program, team leader — 2015 - 2017
- Eberly College of Science, learning assistant — 2016 - 2017
- Springfield benefitting THON, member — 2014 - 2016