



Effect of barley variety on feedlot performance, carcass characteristics, site and extent of digestion, and diet kinetics in steers fed a high concentrate diet
by Darrin Louis Boss

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Animal Science
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Abstract:

Effects of barley variety when used in high concentrate diets were investigated in two trials. Corn (control), Gunhilde barley, Medallion barley, and Harrington barley were evaluated. Trial one evaluated the effects of barley variety on animal performance, carcass characteristics and diet digestion. Eighty crossbred steers were utilized in a completely randomized feedlot trial. Trial two evaluated the effect of barley variety on rate, site and extent of diet digestion. Four abomasally and ruminally cannulated steers were used in a 4 x 4 Latin square designed metabolism experiment. Barley variety did impact feedlot performance in this study. Despite an extremely rapid rate of ruminal digestion, Harrington barley resulted in superior feedlot growth performance and carcass characteristics when compared with Medallion and Gunhilde barleys. It would appear that Harrington barley, which had superior quality grade and feed conversion, may be an acceptable substitute for corn in the Northern Great Plains region until the cost of corn is lower. Kinetics of particulate passage and ruminal digestion of high concentrate diets fed to steers were shown to differ when different barley varieties and corn were used as basal grains. Total tract starch digestibility was greater for steers consuming Harrington, Gunhilde or Medallion barleys compared with those fed com. Intake of digestible starch was 8.2% greater for steers fed diets based on Gunhilde and Harrington barleys, compared with steers consuming Medallion barley. Ruminal retention time was greater for diets based on corn or Medallion barley compared with diets based on Gunhilde or Harrington barley. In addition, all barleys had similar extremely rapid rates of ruminal DM and starch in situ disappearance when compared to corn. It would appear that some barley varieties, in this research Harrington, may be able to compensate for this rapid rate of digestion by supplying additional N in the form of microbial N to the duodenum for digestion and absorption. This study indicates that rapid rumen fermentation of barley may not necessarily result in depressed animal performance. It is evident that additional research is required before recommendations on the best barley variety to feed cattle can be given. It is encouraging though to begin to understand some factors that may affect the digestion kinetics associated with barley variety in high concentrate diets.

**EFFECT OF BARLEY VARIETY ON FEEDLOT PERFORMANCE, CARCASS
CHARACTERISTICS, SITE AND EXTENT OF DIGESTION, AND DIET
KINETICS IN STEERS FED A HIGH CONCENTRATE DIET**

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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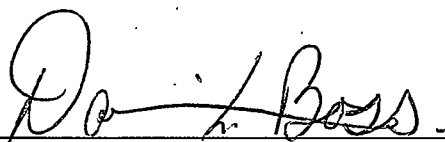
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ABSTRACT

Effects of barley variety when used in high concentrate diets were investigated in two trials. Corn (control), Gunhilde barley, Medallion barley, and Harrington barley were evaluated. Trial one evaluated the effects of barley variety on animal performance, carcass characteristics and diet digestion. Eighty crossbred steers were utilized in a completely randomized feedlot trial. Trial two evaluated the effect of barley variety on rate, site and extent of diet digestion. Four abomasally and ruminally cannulated steers were used in a 4 x 4 Latin square designed metabolism experiment. Barley variety did impact feedlot performance in this study. Despite an extremely rapid rate of ruminal digestion, Harrington barley resulted in superior feedlot growth performance and carcass characteristics when compared with Medallion and Gunhilde barleys. It would appear that Harrington barley, which had superior quality grade and feed conversion, may be an acceptable substitute for corn in the Northern Great Plains region until the cost of corn is lower. Kinetics of particulate passage and ruminal digestion of high concentrate diets fed to steers were shown to differ when different barley varieties and corn were used as basal grains. Total tract starch digestibility was greater for steers consuming Harrington, Gunhilde or Medallion barleys compared with those fed corn. Intake of digestible starch was 8.2% greater for steers fed diets based on Gunhilde and Harrington barleys, compared with steers consuming Medallion barley. Ruminal retention time was greater for diets based on corn or Medallion barley compared with diets based on Gunhilde or Harrington barley. In addition, all barleys had similar extremely rapid rates of ruminal DM and starch in situ disappearance when compared to corn. It would appear that some barley varieties, in this research Harrington, may be able to compensate for this rapid rate of digestion by supplying additional N in the form of microbial N to the duodenum for digestion and absorption. This study indicates that rapid rumen fermentation of barley may not necessarily result in depressed animal performance. It is evident that additional research is required before recommendations on the best barley variety to feed cattle can be given. It is encouraging though to begin to understand some factors that may affect the digestion kinetics associated with barley variety in high concentrate diets.

CHAPTER 1

INTRODUCTION

Barley, grown extensively in the semi-arid environment of Montana, is vitally important in the malting and cereal grain commodity markets. Barley also plays an important role in Montana's livestock industry as an ingredient in winter supplements, and backgrounding and finishing diets. There were 52.8 million bu of barley harvested in Montana in 1992 and 85.8 million bu in 1991, ranking Montana third in the nation in barley production (Mt. Ag. Stat. Serv., 1993). Much of the barley that is produced may not be acceptable for the malting or cereal grain industries and is sold for a lower price as livestock feed.

Montana's largest cash receipts come from the livestock industry (Mt. Ag. Stat. Serv., 1993). Montana cattle ranchers sell over 1,000,000 feeder calves out of state to the cattle finishing industry (Mt. Ag. Stat. Serv., 1993). At the present time Montana does not have a large feedlot industry due to the inability to slaughter large numbers of finished cattle. If at a future date, cattle feedlot operations could be developed in Montana and finish Montana calves with Montana grown barley, the economic benefits to the state's economy would be quite large.

Barley, when compared with corn, provides less energy for cattle (2.06 vs 2.24 Mcal NE_m/kg and 1.40 vs 1.55 Mcal NE_g/kg , respectively; NRC, 1984). However, barley provides a greater amount of crude protein than corn (13.4 % vs 10.1 %, respectively; NRC, 1984). Barley has long been utilized in supplements for ruminants and extensively used in

diets for nonruminants, and has at times been used sparingly in ruminant high concentrate diets. Digestive disorders (bloat and acidosis) created when rapidly fermented grain (Ørskov, 1986) is used in a finishing diet may be part of the reason for its limited use.

It has been the practice in the Midwest region of the United States to finish cattle on corn, the most economical and efficient basal grain source. Corn decreased days on feed, improved feed efficiency, increased carcass weight, and increased quality grade when compared with barley or barley mixes (Anderson and Boyles, 1989). However, barley as the basal grain source has at times produced animal performance and carcass characteristics similar to corn diets (Nichols and Weber, 1988). Barley variety has been reported to differ in chemical composition (starch, nitrogen and phosphorus; McDonald et al., 1991), starch pore location (Fannon et al., 1992) and amylose content, and gelatinization temperatures (Gudmundsson and Eliasson, 1992) which in turn depends upon the location and environment in which it is grown (Kemalyan et al., 1989; Reynolds et al., 1992). The effect of barley variety on nonruminant digestion has been linked to β -glucan content through its impact on viscosity. Increased digesta viscosity potentially decreases nutrient absorption in the small intestine (Wang et al., 1992). Barley variety has been shown to differ in *in vitro* dry matter disappearance (Clark et al., 1987; Kemalyan et al., 1989), animal performance (Ovenell and Nelson, 1992), and neutral detergent fiber digestion (Ovenell et al., 1993). However, until recently, barley variety used has not been reported, or investigated thoroughly in high concentrate diets for cattle.

This study was designed to evaluate:

1. The effect of barley variety upon feedlot performance, carcass characteristics, and diet digestion by steers fed a high concentrate diet.
2. The effect of barley variety upon the rate, site, and extent of digestion in steers fed a high concentrate diet.

CHAPTER 2

LITERATURE REVIEW

High Concentrate Diets

High concentrate diets are traditionally used in management schemes requiring animals to gain large quantities of weight, or to perform at an elevated level, such as a beef steer in the finishing phase or a high milk producing dairy cow. Although dairy diets are slightly lower in concentrate content (60 %) than finishing diets (90 %) they are still considered a high concentrate diet. The larger quantities of forage in dairy diets is important to maintain an acceptable level of butterfat in milk. Sutton et al. (1993) reported that ad libitum feeding of a high quality forage along with an all concentrate ration maintained butterfat levels and increased milk production as the amount of grain increased. The factor driving formulation of high concentrate diets is the enormous amount of energy required for these animals to achieve the desired performance levels. These diets are formulated to provide energy required to maintain the animal (net energy of maintenance, NE_m) and to provide enough residual energy to enable the animal to achieve the performance level desired (net energy of gain/lactation, NE_{gl}). This energy is usually provided in the form of cereal grain.

Corn has traditionally been the most economical and efficient energy source for finishing beef cattle (Anderson and Boyles, 1989). There are many reasons that corn is the preferred cereal grain for high concentrate diets. In the Midwest region of the US, where a large number of the cattle feedlots are located, corn is the cheapest and most widely

available grain. Corn is higher in energy density than barley (2.24 vs 2.06 Mcal NE_m/kg and 1.55 vs 1.40 Mcal NE_g/kg, respectively; NRC, 1984). However, barley is higher in crude protein when compared with corn (13.4 vs 10.1%, DM basis; NRC, 1984). Protein supplements are usually the most expensive diet component. The use of barley may reduce the amount of additional protein needed, thereby reducing diet costs. From a feeding management standpoint corn is one of the safest energy sources. The incidence of bloat, acidosis, and other metabolic disorders are reduced when using a more slowly fermented feedstuff. Barley, oat and wheat starch is rapidly and almost completely fermented in the rumen (> 90% ruminal digestion) whereas sorghum and corn starch is fermented more slowly in the rumen environment (78% ruminal digestion; Waldo, 1973; Ørskov, 1986). By reducing metabolic disorders, morbidity is reduced, keeping animals on full feed and subsequently increasing profit.

Grain sources other than corn, when used with proper management and diet formulation, can be effectively utilized in high concentrate diets. Barley, wheat, and oats can be of equal nutritive value for finishing cattle (Dion and Seoane, 1992), providing adequate energy and producing equal performance (average daily gain, ADG; quality grade, QG; and yield grade, YG), when compared with corn (Nichols and Weber, 1988; Dion and Seoane, 1992). Alternative grain sources have also been investigated in the dairy industry. Studies indicate that barley is an acceptable energy source. In comparison to corn, barley has not impaired milk production or milk quality (butterfat level) in lactating dairy cows when dietary fiber levels were kept constant (DePeters and Taylor, 1985; Grings et al., 1992). These results however, may be drastically impacted by fermentation rates of the

starch fraction of the endosperm, processing and variety of grain source used in the high concentrate diets.

Starch Utilization in Ruminants

Starch consists of amylose, composed of α -1,4-linked glucose molecules, and amylopectin, a branched chain glucose molecule. Amylopectin is made up of both α -1,4-linked and α -1,6-linked branch points. Starch utilization is quite different in ruminants than nonruminants. In nonruminants, the vast majority of starch is digested within the intestinal lumen by α -amylase secreted via the pancreatic duct (Gray, 1992). Very little, if any, starch is hydrolyzed by salivary amylase, but it is rapidly degraded by hydrochloric acid in the stomach. Alpha-amylases bind to the five terminal end glucoses of the starch molecule. The α -amylase then cleaves the starch molecule between the second and third α -1,4-linked glucose residues. Maltose and maltotrioses are the primary products produced during this process. The α -1,6 linkages of amylopectin are impervious to α -amylase (Gray, 1992). Maltases (generic term for all enzymes acting on the products) generally have the ability to cleave off glucose molecules, but are also inhibited by an α -1,6-linkage. The α -1,6-linkages are only cleaved by α -dextrinase. Glucose molecules are then cleaved off sequentially with glucoamylase being the most efficient initially (Gray, 1992). Starch is reduced to glucose because active transport across the intestinal membrane is limited to glucose (Gray, 1992).

In the ruminant the feedstuff undergoes a pregastric fermentation phase in which the ruminal microbes hydrolyze most of the readily available starch as an energy source. Amylase producing microbes are predominate in the rumen of cattle fed a high concentrate

diet (Kotarski et al., 1992). The amount of starch hydrolyzed by the microbes depends upon the type of grain, processing, and diet composition (Kotarski et al., 1992). The digesta then undergoes post-ruminal digestion starting in the abomasum.

Pancreatic and intestinal amylase activity in the ruminant is nearly the same as in the nonruminant (Harmon, 1992). Digestion in the small intestine potentially results in the most efficient use of starch. The small intestine actively transports glucose across the intestinal wall. Glucose has approximately 42% more value energetically when oxidized, than the volatile fatty acids (VFA), produced during ruminal fermentation of starch (Owens et al., 1986).

The concept of post-ruminal starch digestion being most energetically efficient is being challenged. Huntington (1994) reviewed starch utilization in ruminants and reported that the additional flow of microbial protein to the small intestine, and VFA produced from rapidly fermented feedstuffs are more efficiently used than glucose absorbed in the small intestine from feeds that have higher starch bypass. In addition, glucose absorbed and oxidized above the ruminant's requirement is not utilized as efficiently as the absorption of the organic acid fermentation products.

The large intestine also acts as a fermentation chamber, but not as extensively as the rumen (Ørskov, 1986). This secondary fermentation process produces VFA just as fermentation did in the rumen giving the ruminant another opportunity to utilize the starch prior to the excretion in the feces.

Total tract starch digestibilities are usually very high for concentrate diets regardless of the basal grain used (99%, Waldo, 1973; 92%, Owens et al., 1986; 99%, Spicer et al.,

1986). Ruminal fermentation of starch, followed by enzymatic digestion in the small intestine and fermentation in the large intestine, results in digestion of most of the available starch fraction of the feedstuff, and therefore grain type does not substantially impact total tract digestibility. However, site of starch digestion does differ considerably when different basal grains are utilized. Waldo (1973), Ørskov (1986), and Owens et al. (1986) reviewed starch utilization research and reported vast differences in site and extent of starch disappearance dependent upon the grain source.

Corn and sorghum grain have a slower rate of fermentation in the rumen than other grains. Approximately 40% of the corn or sorghum starch presented to the rumen can escape ruminal fermentation (Ørskov, 1986). Oats, wheat, and barley have very rapid fermentation rates in the rumen, and approximately 90% of the starch is digested by the ruminal microbes. The energy sources that result from starch fermentation in the rumen are VFA, leaving only 10% of the starch to be presented to the small intestine for digestion (Waldo, 1973; Ørskov, 1986; Owens et al., 1986). Increasing starch flow to the small intestine for enzymatic digestion should increase energy efficiency (Waldo, 1973). Ruminal starch fermentation has been reported to be 75 to 80% less efficient than glucose absorption in the small intestine (Owens et al., 1986). However, research has shown that equal animal performance levels can be achieved with different grain sources. Animal performance results cannot always be attributed to the starch bypass potential of the grain (Huntington, 1994). This leads to the conclusion that some factor other than grain source may have a great impact on animal performance.

The ruminant digestive tract is designed to remove all available starch, but is there a limit to the amount of starch that can be digested? The rumen environment possibly has the largest starch digesting capacity. The ruminal microbes use the starch as an energy source and produce VFA which are absorbed across the rumen wall. Corn and sorghum starch appear to be less available for bacterial breakdown. The basic structure of the starch granule in the various grains is different, with wheat and barley starch granules being the closest in morphology (McDonald et al., 1991). These differences in morphology may be as simple as surface pores of the starch granule. Fannon et al. (1992) reported that corn and sorghum pores were similar and found randomly over the surface, whereas barley, rye, and wheat pores were found along the equatorial groove. It was concluded that the orientation of surface pores may alter the ability of α -amylases to attack the starch. Pore morphology and location may also affect bacterial attachment and digestion, and may cause corn and sorghum starch to be less readily fermentable in the rumen. Physical properties of starch differ between barley cultivars (Gudmundsson and Eliasson, 1992). The digestibility of barley cultivars may differ due to variation in the ability of ruminal microbes to attach and initiate starch hydrolysis.

McAllister et al. (1993) recently evaluated the barley and corn starch matrix and its effect upon digestibility. They reported the endosperm protein matrix, in which the starch molecules are embedded, is different for corn and barley. The protein matrix rather than the starch itself may cause differences in digestibility, and the endosperm structure apparently has a larger effect upon the digestibility of corn than barley. After treatment with proteases, starch digestion increased more for corn than for barley. Some factor other than the protein

matrix may be more important in limiting access for rumen microbes to barley starch granules.

The small intestine utilizes pancreatic enzymes to break down starches to glucose. Owens et al. (1986) reported that the capacity of the small intestine to digest starch appeared unlimited, as no plateau in glucose level occurred as dietary starch content increased. However, there are limits to the amount of starch that can be digested, and Owens et al. (1986) concluded that some factor other than enzyme activity resulted in the incomplete digestion of starch in the small intestine. Glucose transport sites may be functioning at their maximum rate or the surface area of the grain related to particle size may not allow complete hydrolysis to occur. Huntington (1994) felt that the factor limiting starch digestion may be the amount of pancreatic enzymes secreted. Kreikemeier et al. (1991) infused corn starch into the abomasum of steers and reported digestibility of starch decreased as the amount of starch increased. They also reported the upper limit of starch that can be digested in the small intestine of growing cattle lies between 480 and 960 g/d. Harmon (1992) reviewed research on the capacity of the small intestine to digest starch (corn, barley, and sorghum) and reported a range of 122 to 635 g/d. The starch digestibilities differed widely, ranging from 17.3 to 84.9 % dependent upon the actual level of starch presented. Harmon (1992) and Huntington (1994) concluded dietary energy intake altered the quantity of α -amylase present in pancreatic tissue. Huntington (1994) concluded that as additional starch was fermented in the rumen, the added benefit from increased microbial flow to the abomasum outweighed the effect of reduced bypass of starch. Optimum dietary starch levels should be matched to the production level of the animal (Huntington, 1992). Additional research is

needed on measuring the quantity of pancreatic secretions and their responses to changes in starch level. This would enable ruminant nutritionists to better match dietary starch utilization with energy requirements.

Effect of Processing on Grain Utilization

Processing grains can be as simple as harvesting at a high moisture content. This takes advantage of the immaturity of the grain and results in easier hydrolysis in the rumen. Processing can be as complicated as treatment with formaldehyde in an attempt to alter digestibility through chemical means. All processing affects dry matter (DM) and/or starch digestion by either increasing or decreasing ruminal or post ruminal digestion. Processing has been investigated as a method to increase the ruminal bypass of a rapidly fermented grain such as barley, and to increase the fermentability of slowly digested grains, such as sorghum. The added benefit of processing sorghum is believed to be a result of breaking the very hard seed coat. An excellent review of grain processing effects is presented by Theurer (1986) who reported that corn and sorghum benefited most from processing and barley digestion was only slightly affected by processing. Recent research indicated that sorghum has to be processed in some manner in order to maximize its nutritional value (Streeter et al., 1990 ; Hill et al., 1991; Streeter et al., 1991).

Recent data on the effect of barley processing on digestion by beef cattle are summarized in Table 1. In contrast to Theurer (1986), barley OM and starch digestibility have been increased by grain processing (Table 1). Increasing grain surface area through destructive processing techniques allows a greater opportunity for microbes to attach and

increase digestibility. As grain particle size increased total tract digestibility decreased (Waldo, 1973). Recent research on grain processing has focused on reducing the rapid rate of fermentation seen with barleys. Kennelly and Ha (1990) concluded the superior performance exhibited by the steers fed high moisture rolled or whole barley was the result of a more stable rumen environment when compared to dry rolled barley.

Table 1. The effect on digestibility and finishing cattle performance of various grain processing techniques.

Reference	Grain	Method	Ruminal digestion, %		total tract, %		ADG, kg/d
			OM	Starch	OM	Starch	
Kennelly and Ha, 1990							
	barley	rolled	-	-	71.7 ^{ab}	97.8 ^a	-
	barley	HM [*] -rolled	-	-	76.5 ^a	97.9 ^a	-
	barley	HM-ground	-	-	71.0 ^{ab}	98.5 ^a	-
	barley	HM-whole	-	-	67.7 ^b	89.7 ^b	-
		SE	-	-	1.34	.21	-
		P>F	-	-	.05	.05	-
Zoebell et al., 1992							
	barley	Am [†] whole	-	-	-	-	1.15
	barley	Am rolled	-	-	-	-	1.20
	barley	whole	-	-	-	-	1.15
	barley	rolled	-	-	-	-	1.18
		SE	-	-	-	-	.05
		P>F	-	-	-	-	.18
Zinn, 1993							
	corn	st. ^{**} flaked	60.4	83.9	82.3 ^a	98.3 ^a	1.21 ^a
	barley	dry roll	56.7 ^a	75.8	77.8 ^b	95.0 ^b	1.31 ^b
	barley	st. roll, thick	65.6 ^b	88.2 ^a	80.7 ^{bc}	97.9 ^{bc}	1.29 ^b
	barley	st roll, thin	62.2 ^b	90.1 ^b	80.5 ^{bc}	98.8 ^{bc}	1.28 ^b
		SE	5.2	3.8	1.7	.7	.06
		P>F	.10	.01	.05	.05	.10

^{a,b,c} Means within a column and reference without common superscripts differ.

^{*} High Moisture

^{**} Steam

[†] Not significant

[†] Ammoniated

Zinn (1993) reported that steam flaked corn resulted in lower ADG than found with dry rolled or steam flaked barley. In addition, steam flaked barley actually increased the

NE_m provided to the steer compared with dry rolled barley and tended to increase with flake thickness. It would appear that any type of barley processing is beneficial to animal performance compared to feeding whole barley. However, over processing may occur, Hironka et al., (1992) reported that very finely flaked barley is no better than whole barley when comparing animal performance. Any barley processing technique that gelatinizes the starch stabilizes pH in the rumen environment, as seen in most steam flaking studies.

McAllister et al. (1992) evaluated the effect of formaldehyde treatment on in vitro digestion of barley. These researchers reported that although in vitro dry matter disappearance (IVDMD) of barley was not changed by formaldehyde treatment, the viscosity, often a causative agent in bloat, was reduced enough to be biologically significant. However, McAllister et al. (1990) found treatment with .1 % formaldehyde did slow bacterial fermentation of barley.

Grain processing effects have also been studied in dairy diets. Poore et al. (1993) evaluated dry rolled and steam flaked sorghum and reported an increase in both ruminal and total tract starch digestibilities (48 vs 74%, and 83 vs 98%, respectively) with steam flaking. Nocek (1990) concluded that site of starch digestion could be manipulated by grain processing, but no clear cut evidence existed that increased level of starch flowing to the small intestine increased milk yield or composition. Evidence does exist that post-ruminally digested starch is more efficiently used for milk synthesis than starch digested in the rumen (Nocek, 1990). Huntington (1994) supports this conclusion showing that dairy cattle with high lactational demands, may benefit in higher milk yields more from the additional

microbial protein presented to the small intestine from rapidly fermented feedstuffs than from the glucose that is oxidized after its subsequent absorption in the small intestine.

Effects of Barley Variety

Barley is a unique cereal grain in that it has an extensive number of cultivars (Gudmundsson and Eliasson, 1992). These varieties were initially developed to be either malting or feed barleys. Usually the malting barleys that cannot consistently produce high quality malt are relegated to be feed barleys. Malting barleys can be either 6-row or 2-row, referring to the number of kernels present on the head in a row seen as a person looks down on the head. Malting barleys usually contain between 10 to 13% crude protein (6-row 2.0 to 2.6 % N, and 2-row 1.6 % N) with more preference given to a lower than a higher protein content (Briggs, 1978). Higher nitrogen contents in the kernel increases steeping time (hydration of the kernel, the initial step in the malting process). Once respiration begins, during the germination phase of malting, higher nitrogen levels cause respiration to proceed too rapidly (Briggs, 1978). Possibly the most important characteristic for malting varieties to possess is consistency, to ensure good quality and consistent malt between runs (Briggs, 1978).

During the developmental phase, barley varieties have diverged into two categories, either rich (non waxy) or relatively low (waxy) in amylose content (Gudmundsson and Eliasson, 1992). Barley varieties, waxy or non waxy, have been shown to be different in starch consistency, gelatinization and viscosity (Gudmundsson and Eliasson, 1992). In addition, waxy and non waxy varieties have been shown to differ in physical and

morphological factors (Fannon et al., 1992; Gudmundsson and Eliasson, 1992) and starch granule size and composition (McDonald et al., 1991).

Generally, waxy starch types contain only amylopectin, hydrate faster and have increased rates of in vitro and in vivo digestion when compared with non waxy starch types (Huntington, 1994). Feed barleys have not been selected based on animal performance, instead the variety's lack of consistent malting quality relegates it to feed barley. Animal performance could be impacted to a large degree by these variations in feed quality due to barley variety. However, Huntington (1994) warned that rates of in vitro or in vivo digestion do not always correspond with animal performance.

Impact of variety has been investigated most extensively in sorghum (Streeter et al., 1991; Huntington, 1994). Wester et al. (1992) reported that 48 hybrids of sorghum differed in in vitro starch disappearance. When 4 hybrids were selected, 2 with a slow and 2 with a fast rate of digestion, and used in a lamb feeding trial, no difference was detected in animal performance. However, when 10 hybrids (5 slow and 5 fast) were used in a steer feeding trial, differences were detected between the fastest and the slowest digesting hybrid in steer performance. The fastest disappearing hybrid exhibited 9% faster ADG compared with the slowest hybrid (1.33 vs 1.22 kg/d, respectively).

Barley variety research was initiated in nonruminants, with the objective of using the higher crude protein level associated with barley over corn. Barley varieties were shown to vary in components such as the β -glucan content (Bhatty et al., 1991). Beta-glucan content was shown to affect the viscosity of digesta in chickens, and consequently impaired digestion, but lower concentrations of low density lipoprotein were observed in the blood

(Wang et al., 1992). Ruminant research has primarily focused on the effects barley variety have upon the digestion and performance by animals fed high concentrate diets.

Barley varieties were initially screened for digestion differences by using *in vitro* DM digestibility. Clark et al. (1987) evaluated 16 barley varieties and reported *in vitro* dry matter disappearance (IVDMD) rates ranging between .0618 and .1209. Neutral detergent fiber disappearance (NDFD) rates ranged from .0439 to .4369. It was concluded that IVDMD rate could be a viable method to screen many barley varieties for digestibility differences at one time. Kemalyan et al. (1989) evaluated 8 barley varieties using the *in vitro* technique, and their results agreed with Clark et al. (1987); barley variety did affect IVDMD rate. This variability in IVDMD rate could be related to animal performance if slower digesting varieties present additional starch to the small intestine for enzymatic digestion.

Hatfield et al. (1993) reported that although starch content of barley varieties differed, the site and extent of digestion was not different. When comparing *ad libitum* and restricted feeding of barley varieties to sheep, they concluded that the more desirable feed efficiency achieved with restricted feeding was due to reduced wastage of feed, rather than increased starch presented to the small intestine. Their results do not discredit the theory that barley varieties differ in feed value. The barley varieties they utilized did not differ substantially in ruminal digestibility. This inability to select varieties that differ in ruminal digestibility may be a reason previous research has not been successful in isolating a barley variety that can mimic corn in its higher bypass of starch to the small intestine.

Near infrared reflectance spectroscopy (NIRS) was investigated as a technique to establish the feed quality of barley. Reynolds et al. (1992) evaluated over 1600 barley samples involving at least 78 different varieties. These samples were collected over various locations in Idaho, Washington, and Oregon. These researchers attempted to develop a regression equation to predict the feed value of different barley varieties. They concluded that although NIRS was very easy and simple to use, it could not be used at this time to accurately predict the feed quality of barley. This may be attributed to the fact that researchers have not yet been successful in identifying the relationship between starch content, digestibility and animal performance. Increasing the NIRS' ineffectiveness in predicting feed quality is the lack of a complete regression model relating in situ, or in vitro and in vivo animal performance. These researchers did however conclude that barley variety did differ in feed value, primarily due to different test weights. Feed value of variety was also dependent upon the location of growth and year in which it was grown, agreeing with earlier work by Kemalyan et al. (1989).

Bradshaw et al. (1992) was one of the first to undertake a large cattle feeding trial in which barley varieties were compared. Two hundred and twenty-four steers were utilized in a feeding trial to compare Klages, a 2-row malting barley, and Steptoe, a high yielding 6-row feed barley. Barley variety had no effect upon animal performance and carcass characteristics, but total tract acid detergent fiber (ADF) digestibility was higher for Steptoe than Klages (40.5 vs 31.4%, respectively). Grain processing (dry-rolled, tempered/rolled, ammoniated/rolled or ammoniated/whole) did not affect dry matter intake (DMI), but did affect performance (ADG). When whole barley was fed performance was slightly

depressed. It was concluded that the barley varieties used in this study did not greatly impact feedlot performance, but barley did need to be processed to maximize efficiency.

Ovenell and Nelson (1992) conducted a feeding trial with 144 beef steers to evaluate Andre, Camelot, Clark, Cougar, Harrington, and Steptoe barleys. All barleys were steam rolled prior to feeding. In addition, ruminally and duodenally cannulated steers were used to evaluate the site and extent of digestion of the barley varieties. Animal performance (ADG), and digestibility (DM and starch) were found to differ among barley varieties. In situ NDF digestibility also differed among varieties. It was concluded that barley varieties did differ in feed quality. Steptoe was considered by the researchers to be a poorer feed barley than the others tested due to decreased animal performance and digestibility. Clark and Andre were considered better feed barleys due to increased animal performance. However, on review of the data, this conclusion may be a bit premature. Average daily gains were similar (1.4 kg/d) for all barley varieties except Cougar (1.3 kg/d). Clark had one of the least desirable feed efficiencies and was not different from Steptoe (6.9 kg feed / kg gain). Feed efficiency for Andre was the same as all others (avg 6.5 kg feed / kg gain). No difference in carcass quality or yield grade was detected. No difference was detected between the barley varieties in either ruminal or total tract digestibility of organic matter (OM), energy, or starch. Neutral detergent fiber ruminal digestibility was not different for the varieties, but total tract NDF digestibility was highest for Andre and intermediate for Clark. An alternative conclusion would be that barley variety affected total tract NDF digestion and intake. No recommendations on the feed quality of the barleys utilized in this study could be made based on the data presented.

Ovenell et al. (1993) conducted a similar experiment using Boyer, Camelot, Clark, Harrington, Hesk, and Steptoe barley varieties. They fed 144 steers a diet which contained approximately 77 % barley (DM basis) for 119 d. It was concluded that barley variety differed in NDF digestibility and feed value. The more desirable varieties for finishing beef steers were considered by the researchers to be Harrington and Camelot. These two varieties supported intermediate animal performance in the previous study. This supports the conclusions that feed quality of barley variety may be influenced by geographic location and year of harvest (Kemalyan et al., 1989; Reynolds et al., 1992) and that a more completely ruminally digested feedstuff is more efficient energetically to the finishing beef steer (Huntington, 1994).

Feng et al. (1994) used five ruminally and duodenally cannulated steers to evaluate the effects of starch level and barley variety on digestive function in forage-based diets. Russell and Steptoe barleys were compared, with corn serving as the control. Barley supplements were higher in both ruminal and total tract starch digestion than the corn supplement. Nitrogen flow to the small intestine also followed this trend with all barley treatments supplying increased amounts of nitrogen. Corn supplemented steers had the lowest NDF intake. These results support conclusions by Reynolds et al. (1993) that barley diets provided increased carbohydrate digestion and increased microbial growth compared to a corn diet. In addition, a greater quantity of protein supplied to the small intestine may make barley equal to or superior to corn in forage-based diets. Effective supplementation of poor quality hay diets requires that the availability of protein and energy be balanced to insure maximum animal response (Sunnold et al., 1993). Although the diets fed in this

study were not high concentrate diets (<35%) it illustrates a need for further research into the utilization of protein and energy, and their potential interactions in high concentrate diets.

Hunt et al. (1994) fed diets similar to those fed by Feng et al. (1994), and reported that barley variety did not affect growth performance or carcass characteristics. However, barley diets with high levels of starch had a depressed intake. The depressed intakes may be related to fluctuating pH levels. Kennelly and Ha (1990) and Hironaka et al. (1992) observed a less stable rumen environment resulting from fluctuations in pH levels with high levels of starch in barley diets.

Hepton et al. (1994) evaluated the effect starch and fiber content of barley variety had on growth in beef steers. These researchers evaluated the effect of the hull fraction as the major source of variation in feed value between barley varieties. They concluded that as starch level increased a positive linear correlation existed with digestibility. Animal performance responded quadratically to increasing starch level, and was greatest for the 100% barley treatment versus any treatment with pearled barley or hulls added. No difference was seen in animal performance between treatments containing pearled grain with higher digestibilities, and hulls with slower digestibility. Therefore, rapidly degradable grain sources may not always have a negative impact on animal performance. Ovenell and Nelson (1992) and Ovenell et al. (1993) reported that some very highly digestible barley varieties supported animal performance similar to that found with less digestible varieties.

Barley breeders have recently become interested in the feed value of barley and the factors influencing its digestibility and resultant animal performance when used in high concentrate diets. Gibson et al. (1994) proposed that if the trait(s) that affects barley digestibility can be linked to a specific chromosome, then barley breeders can begin a breeding program to increase the feed value of barley varieties. These researchers utilized in situ DM and starch digestibility to screen 150 double haploid lines from the cross of Steptoe and Morex. The lines were evaluated for in situ DM and starch disappearance rates, agronomic measures and malting characteristics and mapped to known genetic markers in the barley genome. They were then correlated to each other. From this study and others associated with it they have determined that genetic differences in barley impact digestibility. It is evident from the conflicting results presented that additional research into barley variety and how it affects digestibility and animal performance is needed. It is encouraging that barley breeders and animal scientists are working together to produce a better feed barley. Although research has shown barley at times to be equal to corn in feed quality, the development of a barley variety that can consistently equal corn in animal performance, maintain ruminal pH, and decrease metabolic disorders, has not been achieved. If this can occur the barley and livestock industries may benefit economically.

CHAPTER 3

EFFECTS OF BARLEY VARIETY OR CORN ON FEEDLOT PERFORMANCE,
CARCASS CHARACTERISTICS, AND DIET DIGESTION BY STEERSIntroduction

Barley is an important agronomic crop in Montana with approximately eighty-five million bushels produced annually (Montana Agricultural Statistics Service, 1993). Barley also plays an important role in the livestock industry as an ingredient in backgrounding and finishing diets, and in winter supplements across the Northwest.

Corn has traditionally been the most profitable and efficient feed grain for finishing beef cattle (Anderson and Boyles, 1989). The ruminal bypass of the starch in corn has been thought to be a primary factor affecting performance (Waldo, 1973; Ørskov, 1986). Barley has been shown to be highly fermentable in the rumen, allowing very little of the starch to escape ruminal fermentation for digestion in the small intestine (Ørskov, 1986). However, barley diets have been shown to provide similar animal performance and carcass characteristics compared to corn diets (Nichols and Weber, 1988; Bradshaw et al., 1992). More recently, it has been demonstrated that barley variety can affect IVDMD rate (Clark et al., 1987; Kemalyan et al., 1989), animal performance (Ovenell and Nelson, 1992) and NDF digestion (Ovenell et al., 1993). This study was designed to evaluate the effects of barley variety upon feedlot performance, carcass characteristics, and diet digestion by steers fed a high concentrate diet.

Materials and Methods

Eighty Angus x Hereford steers (average initial weight 287 kg) were assigned to one of 16 pens based on equal pen weight in a completely randomized design. The four dietary treatments were: 1) corn; 2) Gunhilde barley (Gun); 3) Medallion barley (Med); or 4) Harrington barley (HAR) as the basal grains in high concentrate finishing diets. Harrington is a 2-row cultivar grown extensively as malting barley, while Gunhilde was developed as a feed barley in Europe. Medallion is a high yielding 6-row cultivar, developed as a feed barley and genetically similar to Steptoe barley.

Diets were balanced to be isocaloric (1.87 Mcal/kg NE_m , 1.23 Mcal/kg NE_g) and isonitrogenous (12.6% CP). The corn utilized in the trial was purchased at a local grain elevator in Bozeman, MT. The barleys were grown at the Southern Agricultural Research Center, Huntley, MT, under irrigation. All grains were coarsely cracked prior to feeding. Low quality grass hay (<7.0 % CP) was chopped to 5.1 cm prior to mixing diets. Ingredient and nutrient composition of the diets are presented in Table 2.

Table 2. Composition and nutrient content of finishing diets containing corn, Gunhilde barley (GUN), Medallion barley (MED), or Harrington barley (HAR) as the basal grains.

Item	Barley variety			
	Corn	GUN	MED	HAR
..... % DM basis				
Ingredient				
Barley	---	80.00	80.00	80.00
Corn	70.00	---	---	---
Grass hay	20.50	12.70	12.70	12.70
Canola oil	.15	.15	.15	.15
Soybean meal	3.75	2.15	2.10	2.40
Urea	1.00	.70	1.00	---
Molasses, dry	1.25	1.25	1.25	1.25
Limestone	.50	.59	.70	.75
Sodium chloride	.20	.20	.20	.20
Potassium chloride	.16	.16	.16	.16
Dicalcium phosphate	1.09	.70	.34	.99
TM premix ^a	.05	.05	.05	.05
Sodium bicarbonate	1.30	1.30	1.30	1.30
Vitamin premix ^b	.01	.01	.01	.01
Tylan, 88 mg/kg ^c	.0125	.0125	.0125	.0125
Rumensin, 132 mg/kg ^d	.024	.024	.024	.024
Nutrient				
Ash, %	5.57	5.69	5.50	6.09
Gross energy, Kcal/g	4.16	4.12	4.15	4.10
Crude protein, %	12.73	13.05	13.65	11.04
Acid detergent fiber, %	11.19	10.25	10.20	10.64
Calcium, %	.54	.42	.44	.53
Phosphorous, %	.49	.51	.44	.56
Starch, %	46.48	38.91	36.07	40.67
NE _m , Mcal/kg ^e	1.87	1.87	1.87	1.87
NE _g , Mcal/kg ^e	1.23	1.23	1.23	1.23

^a Trace mineral premix contained: 20.0% Mg, 6.0% Zn, 4.0% Mn, 5.0% Fe, 2.7% S, 1.5% Cu, .11% I, .01% Se, and .01% Co.

^b Vitamin premix contained: 30,000 IU/g Vitamin A, 6,000 IU/g Vitamin D, and 7.5 IU/g Vitamin E.

^c Elanco Products Co., Indianapolis, IN.

^d Hoffman-LaRoche Inc., Nutley, NJ.

^e Calculated based on NRC (1984).

Steers were implanted with Ralgro® on day one of the trial. A 28-d adaptation period was used to adjust steers to the high concentrate diets. During this period the dietary concentrate:forage was increased .23 kg/d. After the 28-d adaptation period, the steers (average weight 309 kg) were fed for an additional 168 d. Steers were given ad libitum access to feed which was offered once daily between 0500 and 0700. Feed bunks were inspected before feeding and feed offered adjusted daily to allow ad libitum access. Feed offered was recorded daily and the feed refusals were weighed and recorded every 14 d. Weekly grab samples of feed ingredients were taken throughout the experiment. Water and TM salt blocks were offered ad libitum throughout the trial. Initial and final unshrunk weights were obtained on two consecutive days and averaged. Animal weight change was measured every 28 d during the experiment. Dry matter intake, ADG and feed conversion (kg feed / kg gain) were calculated. Four steers were removed from the experiment (2 bloat, 1 acidosis, 1 high mountain disease). Performance calculations were adjusted for the removal of these steers.

Fecal grab samples were taken from each steer after 56 d (early), 84 d (mid) and 140 d (late) on feed, and composited by pen. Acid insoluble ash (AIA; Van Keulen and Young, 1977) was used as an internal marker to estimate fecal output. This allowed the calculation of DM, starch, and CP total tract digestibility, and daily digestible intakes. Prior to analysis, samples were ground in a Wiley mill to pass a 1-mm screen. Diet samples collected weekly were composited on a equal weight basis. Analyses performed included: DM, CP, OM (AOAC, 1990), ADF (Van Soest et al., 1991), GE in a adiabatic bomb calorimeter, total

starch (Megazyme, Sidney, Australia), Ca and P (AOAC, 1990). Fecal grab samples were analyzed for DM, OM, CP and total starch.

The steers were slaughtered when visual estimates indicated that 80% would grade Choice. Hot carcass weights were obtained on the day of slaughter; other carcass measurements, were taken after a 24-h chill. Kidney, heart and pelvic fat, marbling and preliminary quality and yield grades were assigned by a USDA grader. A marbling score of 4 represented small marbling, the minimum required for the low choice quality grade, with a 5 representing modest marbling. Yield and quality grades were calculated with a quality grade of 12 representing low choice, and 13 representing average choice.

Data were analyzed as a completely randomized design with a one-way analysis of variance using the GLM procedure of SAS (1993), with the model $y_{ij} = \mu + T_i + \epsilon_j$, (i = treatments (4), j = pens within each treatment (4), μ = overall mean, T = treatment effect, ϵ = is the overall error effect). Pen was the experimental unit for all performance data. Least square means were separated by the LSD method (SAS, 1993) if the treatment F-test was significant ($P < .10$). Least square means and the associated standard errors are reported.

Results and Discussion

Steers consuming the corn diet gained 12.6% faster ($P = .002$) than steers consuming HAR or MED over the 168-d feeding period (Table 3). Steers fed HAR gained 10.2% faster ($P = .002$) than steers fed GUN, while no difference in ADG was detected between GUN and MED. Cumulative ADG by days on feed is presented in Figure 1. This figure represents the

ability of HAR to sustain cumulative ADG equal to corn until the final 28 d of the experiment.

Table 3. Feedlot performance of steers fed corn, Gunhilde barley(GUN), Medallion barley(MED), or Harrington barley (HAR) based high concentrate diets

Item	Barley variety				SE	P > F
	Corn	GUN	MED	HAR		
Pens, no.	4	4	4	4	--	--
Steers, no.	19	19	18	18	--	--
Initial wt, kg	286	286	288	287	.6	.4612
Final wt, kg	550 ^c	499 ^a	512 ^a	527 ^b	5.6	.0002
ADG, kg/d	1.43 ^c	1.18 ^a	1.23 ^{ab}	1.30 ^b	.039	.0020
DM Intake, kg/d	10.4 ^b	7.8 ^a	7.7 ^a	8.6 ^a	.31	.0002
Feed:gain	7.36 ^b	6.79 ^a	6.28 ^a	6.59 ^a	.221	.0303
Diet cost, \$/100 kg [†]	13.11	11.48	11.55	11.51	--	--
Cost:gain, \$/100 kg	93.25 ^b	75.00 ^a	69.00 ^a	72.75 ^a	.033	.001

^{a,b,c} Means in a row without a common superscript differ ($P < .05$).

[†] Cost includes only feed cost:

Corn grain	\$11.77 / 100 kg
Barley grain	\$ 9.88 / 100 kg
Grass hay	\$ 7.66 / 100 kg
Corn supp.	\$34.83 / 100 kg
Gun supp.	\$36.54 / 100 kg
Har supp.	\$35.88 / 100 kg
Med supp.	\$35.90 / 100 kg

During the adaptation period the corn fed steers had a higher ($P = .04$) ADG (.94 kg/d) than any of the barley fed steers (.72 kg/d). After full feed was offered, from d 0 to 28 the corn fed steers gained 8% faster (1.21 kg/d, $P = .05$) than the HAR fed steers (1.12 kg/d) and 33% faster than either GUN or MED (.91 kg/d) fed steers, with the HAR fed steers gaining 23.1% faster than GUN or MED fed steers. From d 28 to 84 the corn and HAR fed steers gained 23.7 % faster (1.46 kg/d, $P = .005$) than the GUN and MED (1.18 kg/d) fed steers.

Between d 84 and 140 d, the corn and HAR fed steers gained faster ($P = .007$; 1.48 and 1.35 kg/d, respectively) than the GUN fed steers (1.18 kg/d), with Med fed steers being intermediate (1.30 kg/d) and not different ($P > .10$) from HAR or GUN fed steers. During the final 28 d, the corn fed steers gained 12.6% faster (1.43 kg/d, $P = .004$) than either HAR or MED (1.27 kg/d) and 18.0% faster ($P = .004$) than the GUN fed steers (1.18 kg/d). The MED and GUN fed steers did not differ ($P > .10$) in ADG during this time.

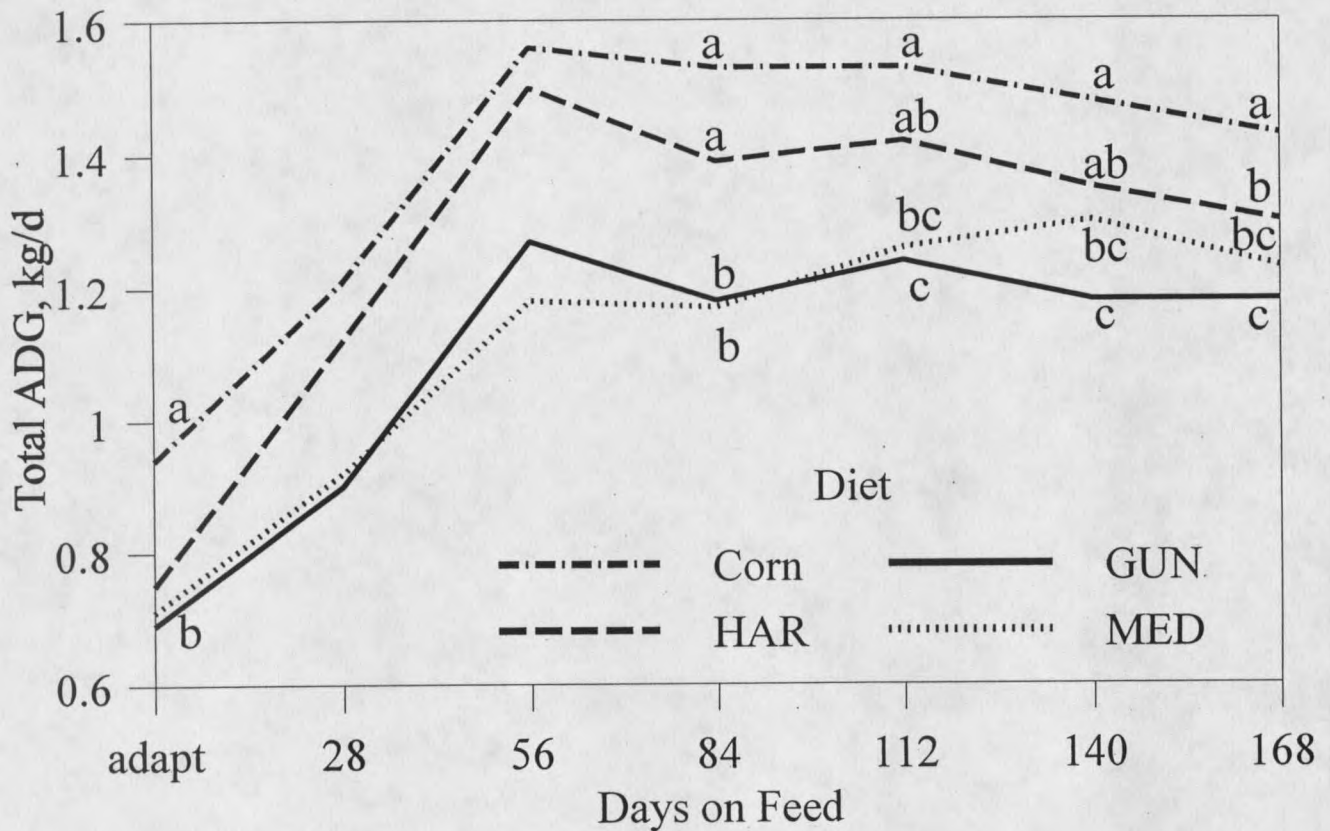


Figure 1. Cumulative ADG of steers fed corn, Gunhilde barley (GUN), Medallion barley (MED), or Harrington barley (HAR) based high concentrate diets.

Steers consuming corn had greater ($P = .0002$) DM intakes, than those fed HAR, MED or GUN (Table 3). In an associated metabolism trial, Boss and Bowman (1994) reported lower ruminal fluid pH levels in barley fed steers, compared with a more constant pH seen in steers fed corn. This fluctuation in pH may have contributed to the lower DM intakes observed in the barley fed cattle.

Steers consuming corn had poorer ($P = .0303$) feed conversion than steers fed HAR, MED, or GUN. Our feedlot growth performance results agree with Ovenell et al. (1993) who reported HAR was a superior feed barley for steers consuming a high concentrate diet. These conclusions also support the theory proposed by Huntington (1994) that the energy derived from products (VFA) of rapidly fermented feedstuffs is more efficient than glucose absorbed in the small intestine which is oxidized. Medallion is genetically similar to Steptoe, a cultivar that has been shown to be a less desirable barley variety for finishing steers (Ovenell and Nelson, 1992; Ovenell et al., 1993). The ADG of steers in the present study was slightly lower than the range reported by Ovenell and Nelson (1992) and Ovenell et al. (1993). This may be related to the lower DM intakes of the steers on this study, potentially related to grain processing. Ovenell and Nelson (1992) and Ovenell et al., (1993) steam rolled the barley prior to feeding. Steam processing or other less destructive grain processing has been shown to maintain a more stable pH in the rumen (Kennelly and Ha, 1990; Zinn, 1993).

In this study corn had superior overall growth performance (ADG), however the cost of the diet may be a factor to be considered in the region. The cost of gain paralleled feed conversion. The corn diet cost \$.21/kg.gain more ($P = .001$) than the barley diets (Table 3).

In much of the Pacific Northwest, the growing season is too short to consistently produce corn, and most of the corn has to be shipped in adding to the cost of the diet.

Hot carcass weight was 22.6 kg heavier ($P = .0001$) for steers consuming corn compared with steers consuming HAR, GUN and MED (Table 4). Backfat thickness was .37 cm greater ($P = .0031$) for steers fed corn and HAR compared with those fed GUN and MED. No differences ($P = .7299$) were found in longissimus muscle area, with all steers averaging 77.68 cm². Yield grades were higher ($P = .0019$) for steers fed corn and HAR compared with those fed GUN and MED. Only 2 carcasses had yield grades of 4. Marbling score and quality grade were higher ($P = .007$) for steers fed HAR compared with corn, GUN, and MED. Only two carcasses graded Select, with 9 grading Prime and the balance grading Choice. These results conflict with Anderson and Boyles (1989) who reported corn had superior quality grades when compared with barley fed steers, and disagrees with Ovenell and Nelson (1992) and Ovenell et al. (1993) who reported that barley variety did not affect most carcass characteristics, YG and QG. However, these researchers fed their steers approximately 50 d less. Carcass characteristics have previously been reported to be unsensitive to differences in basal grains and grain processing (Zinn, 1993). Carcass characteristics reported here illustrate that days on feed may be more important than grain source fed in determining carcass quality. When evaluating the growth performance and carcass characteristics, HAR appeared to be a superior feed barley and the fact that marbling and QG were superior to corn may positively impact net profit.

Table 4. Carcass characteristics of steers fed corn, Gunhilde barley (GUN), Medallion barley (MED), or Harrington barley (HAR) based diets

Item	Corn	Barley Variety			SE	P > F
		GUN	MED	HAR		
Hot carcass wt, kg	318.5 ^c	291.2 ^a	293.9 ^a	302.6 ^b	5.19	.001
KHP fat, % [†]	2.18 ^c	1.89 ^{ab}	1.87 ^a	2.08 ^{bc}	.088	.0456
Backfat, cm	1.07 ^b	.64 ^a	.61 ^a	.94 ^b	.099	.0031
Longissimus area, cm ²	78.1	77.4	79.4	76.8	1.78	.7299
Marbling score [‡]	4.65 ^a	4.17 ^a	4.11 ^a	5.42 ^b	.297	.0074
Quality grade [‡]	12.65 ^a	12.17 ^a	12.11 ^a	13.42 ^b	.297	.0074
Yield grade	2.79 ^b	2.10 ^a	1.99 ^a	2.60 ^b	.163	.0019

^{a,b,c} Means in a row without a common superscript differ ($P < .05$).

[†] % Kidney, heart and pelvic fat.

[‡] Marbling score: Slight = 3, Small = 4, Modest = 5 etc.

[‡] Quality grade (calculated): Select = 11, Choice⁻ = 12, Choice^o = 13, Choice⁺ = 14 etc. Calculated yield grade.

In vivo digestibilities were calculated by period (early, mid, late), but no treatment x period interaction ($P > .10$) was detected, therefore, only treatment means are presented (Table 5). In vivo DM and starch digestibilities were 11.2 and 8.8% lower, respectively, for corn compared with the three barley diets ($P = .0001$). Crude protein digestibility was lowest ($P = .0001$) for steers fed corn (69.1%), intermediate for those fed HAR (74.1%), and highest for steers consuming GUN and MED (81.1 and 80.8%, respectively). In an associated metabolism study, in situ DM digestibility of the individual grains followed the same trend as in vivo DM digestibility of the entire diets, with corn grain having an 8.1% lower ($P = .03$) digestibility compared with the three barley grains (Boss and Bowman, 1994). Rate of in situ DM digestion was 83% slower ($P = .0940$) for corn ($.0538 \text{ h}^{-1}$) compared with HAR and GUN ($.2778$ and $.3723 \text{ h}^{-1}$), although no difference was detected between the intermediate, MED ($.2241 \text{ h}^{-1}$) and the other treatments (Boss and Bowman,

1994). These results agree with Ørskov (1986) who reported that corn digestion was slower and less complete than barley digestion in the rumen.

The ADG rankings followed the rankings for total starch in the diets and digestible starch intakes (Table 5). The corn fed steers had greater digestible DM intakes ($P = .001$) when compared to the barley fed steers. The steers consuming the corn diet had an 18.4% greater digestible starch intake ($P = .0001$) than the steers consuming HAR. This increase in digestible DM intake and digestible starch intake may be contributing to the 18% greater ADG observed for the steers fed corn. The HAR fed steers exhibited intermediate ADG and digestible starch intakes. The conflicting data between performance and ruminal digestion make it impossible to contribute the superior animal performance to ruminal digestible starch content in the diet.

Table 5. Nutrient digestibilities by steers fed corn, Gunhilde barley (GUN), Medallion barley (MED), or Harrington barley (HAR) based high concentrate diets

Item	Corn	Barley variety			SE	Pr > F
		GUN	MED	HAR		
In vivo digestibility, %						
Dry matter	71.2 ^a	80.9 ^b	80.8 ^b	78.9 ^b	.82	.0001
CP	69.1 ^a	81.1 ^c	80.8 ^c	74.1 ^b	1.02	.0001
Starch	89.8 ^a	97.9 ^b	98.9 ^b	98.8 ^b	.52	.0001
Digestible intake [‡] , kg/d						
DM	7.77 ^b	6.86 ^a	6.82 ^a	7.09 ^a	.078	.0011
CP	.95 ^b	.91 ^b	.91 ^b	.73 ^a	.013	.0001
Starch	4.5 ^c	3.5 ^a	3.3 ^a	3.8 ^b	.041	.0001

^{a,b,c} Means in a row without a common superscript differ ($P < .05$).

[†] Nutrient * % in vivo digestibility.

Implications

Barley variety did impact feedlot performance in this study. Despite an extremely rapid rate of ruminal digestion, Harrington barley resulted in superior feedlot growth performance and carcass characteristics when compared with Medallion and Gunhilde barleys. It should be noted that performance was confounded by DM intakes, digestible DM intakes and digestible starch intakes, with corn fed steers having the highest ADG. However, it would appear that Harrington barley, which had superior quality grade and feed conversion, may be an acceptable substitute for corn in this region until the cost of corn is lower. In future research, added attention should be made to insure closer intakes to better compare barley variety to corn and its applicability to finishing steers on high concentrate diets. These data suggest that rapid ruminal digestion having a negative influence on animal performance may not be true. More research is needed to quantify and evaluate barley characteristics that influence animal performance.

CHAPTER 4

EFFECTS OF BARLEY VARIETY OR CORN ON RATE, SITE AND EXTENT OF
DIGESTION IN STEERS CONSUMING A HIGH CONCENTRATE DIETIntroduction

Barley is the primary small grain grown in much of the semi-arid region of North America. Montana produces approximately 85 million bushels annually, ranking it third in the nation (MT Agricultural Statistics Service, 1992). Barley is important as an ingredient in backgrounding and finishing diets, and winter supplements, however, corn has traditionally been the most profitable and efficient feed grain for finishing beef cattle (Anderson and Boyles, 1989). Anderson and Boyles (1989) reported decreased days on feed, improved feed efficiency, increased carcass weights, and increased quality grades for corn fed steers when compared with barley fed steers. The ruminal bypass of corn starch has been thought to be the primary factor affecting animal performance (Waldo, 1973; Ørskov, 1986; Owens et al., 1986). Barley has been shown to be highly fermentable in the rumen, allowing very little of the starch to escape and be digested in the small intestine (Ørskov, 1986; Owens et al., 1986). Digestion in the small intestine potentially results in the most efficient use of starch. The small intestine actively transports glucose across the intestinal wall. Glucose has approximately 42% more value energetically when oxidized, than the volatile fatty acids (VFA) produced during ruminal fermentation of starch (Owens et al., 1986). If a barley variety can be identified that has the potential to present increased

amounts of starch to the small intestine, as in corn, the economic benefits to the barley and livestock industries may be substantial.

Barley diets have resulted in animal performance and carcass characteristics similar to corn diets (Nichols and Weber, 1988; Bradshaw et al., 1992). Recently, it has been demonstrated that barley variety may affect IVDMD (Clark et al., 1987; Kemalyan et al., 1989), NDF digestion (Ovenell et al., 1993), and animal performance (Ovenell and Nelson, 1992). Conflicting results in animal performance and starch kinetics may result from research not focusing on barley variety, and are difficult to interpret as often the variety used is not reported. This study was designed to evaluate the effect of corn or barley variety in high concentrate diets, on rate, site and extent of digestion.

Animal Surgery

Four Angus x Hereford steers with ruminal and abomasal cannulae were utilized in a 4 x 4 Latin square designed experiment to evaluate the effect of barley variety when fed in a high concentrate diet. Surgical and care protocols for all research animals on this study were approved by the Montana State University Animal Care Committee. All necessary steps, including tranquilization, regional or local anesthesia, were used to alleviate or minimize pain. Steers were removed from feed for 24 h and water for 12 h prior to surgery.

A rumen cannula (i.d. 7.62 cm; Bar Diamond, Parma, ID) was inserted into the left paralumbar fossa of the steer approximately 4 cm below the transverse processes of the lumbar vertebrae and 4 cm behind the 13 rib. Steers were anesthetized with a 16 gauge needle full of small animal Rompum and 1 cc of Butorphenol iv after being restrained in a

working chute and head gate. Butorphenol was used to reduce the amount of Lidocaine required when performing two surgeries on a single day. The surgical site was clipped and shaved, washed with soap and water, rinsed with a dilute iodine solution, and sprayed with an alcohol spray prior to administration of a local anesthesia. Lidocaine (2%, 50 cc) was administered in a reversed "7" just anterior to the surgical site via subcutaneous, intramuscular, and intradermal routes. An additional 25 cc was administered ventrally and dorsally to each of the first 4 transverse processes of the lumbar vertebrae. Approximately 10 minutes elapsed prior to the initiation of surgery. A circular (10 cm diameter) piece of epidermis was removed, followed by the manual blunt separation of the three muscle layers and peritoneum to expose the rumen. Approximately 5 cm of the rumen was exteriorized, and 8 stay stitches (nonabsorbable suture) were located equidistant around the circular epidermal area attaching the rumen to the epidermal layer. Continuous stitching with an absorbable suture was performed between each stay stitch. A vertical incision in the rumen wall was made with a scalpel, the incision terminating 1 cm from each side of the epidermal layer. The cannula was soaked in hot water to soften the rubber, inverted and placed in the rumen incision site. The 7.62 cm i.d. smaller cannula remained in the rumen for 30 d after the initial surgery, ensuring a very tight fit when a larger (10.2 cm i.d., Bar Diamond) cannula was inserted to facilitate collections.

To install the abomasal cannula, the steer was placed in a left lateral recumbency position. An area approximately 10 cm posterior to the last rib at the level of the costochondral junction and parallel to the rib was prepared for surgery similar to the preparation for the rumen surgery. Lidocaine was administered, in a "7" to anesthetize the

local surgical area. A 15 cm paracostal laparotomy was performed to gain access to the peritoneal cavity. After location of the abomasum, the abomasum was exposed through the incision. The incision's surrounding area was packed with sterile gauze sponges moistened with sterile saline solution. A longitudinal incision (2.5 cm) along the abomasum was made avoiding the pyloric region. A simple Plastisol "T" cannula (i.d. 2.54 cm, University of Missouri, Columbia, MO) was placed in the abomasum and located towards the ventral end of the incision. Using absorbable suture, a purse string pattern was sutured around the incision site and cannula, the purse string was pulled tight and tied. The cannula was exteriorized (approximately 3.8 cm) through the incision site. After removal of the sponges, the peritoneum and muscle layers were sutured with absorbable suture material. The epidermal layer was sutured with nonabsorbable suture material. Retainer rings and plugs were put in place and the steer was allowed to recover from anesthesia. For 24 h following surgery the steers were housed in individual clean pens (5.8 m²). The steers were offered clean water and high quality alfalfa hay.

Steers were treated with Combiotic (10 ml, Pfizer Animal Health, New York, NY) by an i.m. injection daily for 3 d after surgery. Postoperative care included washing the cannulas, applying topical medication (Furacin, Norden Laboratories, Smith-Cline Co., Lincoln, NE) and monitoring rectal temperature for 7 d after surgery. Epidermal sutures were removed approximately 14 d after the surgery. Steers were allowed to recover and adapt to the cannulas for a minimum of 60 d before collections began.

Material and Methods

Throughout the trial steers were housed in individual 15 m² pens bedded with straw. Water and trace mineral salt blocks were available free choice. Automatic waterers were monitored and cleaned as required. Pens were scraped and cleaned on a regular basis and rebedded only during the first week of the adaptation period.

The dietary treatments compared were 1) corn; 2) Gunhilde barley (GUN); 3) Medallion barley (MED); or 4) Harrington barley (HAR) as the basal grains in high concentrate diets. Gunhilde barley (8.0 kg/hl) is a European feed barley, while Medallion barley (7.8 kg/hl) is a 6-row cultivar developed as a feed barley and genetically related to the variety Steptoe. Harrington barley (7.8 kg/hl) is primarily grown as a 2-row malting barley. The corn (9.0 kg/hl) utilized in the trial was purchased at a local elevator in Bozeman, MT. Barleys were grown under irrigated conditions at the Southern Agricultural Research Center, Huntley, MT.

Diets were balanced to be isocaloric (1.87 Mcal / kg NE_m, 1.23 Mcal / kg NE_g) and isonitrogenous (12.6% CP). All grains were coarsely cracked through a roller mill prior to feeding. Low quality grass hay (< 9.0% CP) was chopped to 5.1 cm prior to mixing diets. Ingredient composition of the diets is presented in Table 6.

Steers were limit fed these diets (1 to 1.5% BW/d) in 2 portions, half at 0600 and half at 1800, attempting to achieve a steady state condition. Each experimental period of the Latin square consisted of 21 d, with 14 d for diet adaptation followed by 7 d for sample collection. Diet changes from one period to the next were done on a step wise substitution basis. The new diet was substituted at 25 %/d until the new diet made up 100% of the diet.

The diet substitution was done in the initial 4 d of the adaptation period. Feed samples were collected twice daily at feeding during the 7-d collection periods, and composited within steer and period. Feed samples were ground in a Wiley mill to pass a 1-mm screen and analyzed for DM, N, OM (AOAC, 1990) and total starch (Megazyme, Sidney, Australia).

Steers were dosed twice daily via the rumen cannula prior to feeding with 5 g Cr_2O_3 in gelatin capsules (dose = 10 g/d) throughout the experiment as a marker to estimate abomasal or fecal output. Steers were pulse dosed via the rumen cannula with 350 g of Yb-labeled grain (Poore et al., 1991) on day one of the collection period as a digestion kinetics marker. Fecal and abomasal grab samples were taken at 0, 3, 6, 9, 12, 15, 18, 21, 24, 30, 36, 42, 48, 54, 60, and 72 h post-dosing.

Fecal samples were dried in a forced air oven (50°C) for 72 h, and then ground in a Wiley mill to pass a 1-mm screen. A portion of the hourly fecal samples was composited on a DM basis within steer and period. Fecal composites were analyzed for DM, OM, N, total starch, and Cr (Hill and Anderson, 1958) to estimate fecal output. Abomasal samples were divided in half on a volume basis at the time of collection. One abomasal sample was lyophilized, and the other was frozen for later ammonia analysis (AOAC, 1990). A portion of the hourly lyophilized abomasal samples were composited on an equal dry weight basis and analyzed for DM, N, OM, total starch and Cr. Hourly dried fecal, lyophilized abomasal and Yb-labeled grain samples were analyzed for Yb content by atomic absorption spectrophotometry (Ellis et al., 1982). The hourly abomasal and fecal Yb concentrations were fitted both a one- and two-compartment model (Ellis et al., 1979) to estimate particulate flow rate, retention time, time delay (Tau) and DM output.

Table 6. Composition and nutrient content of feedlot diets with corn, Gunhilde barley (GUN), Medallion barley (MED), or Harrington barley (HAR) as the basal grains

Item	Barley Variety			
	Corn	GUN	MED	HAR
..... % DM basis				
Ingredient, %				
Barley	---	80.00	80.00	80.00
Corn	70.00	---	---	---
Grass hay	20.50	12.70	12.70	12.70
Canola oil	.15	.15	.15	.15
Soybean meal	3.75	2.15	2.10	2.40
Urea	1.00	.70	1.00	---
Molasses, dry	1.25	1.25	1.25	1.25
Limestone	.50	.5935	.70	.75
Sodium Chloride	.20	.20	.20	.20
Potassium Chloride	.16	.16	.16	.16
Dicalcium phosphate	1.094	.70	.344	.9935
TM premix [†]	.05	.05	.05	.05
Sodium bicarbonate	1.30	1.30	1.30	1.30
Vitamin Premix [‡]	.01	.01	.01	.01
Tylan, 88 mg/kg	.0125	.0125	.0125	.0125
Rumensin, 132 mg/kg	.024	.024	.024	.024

[†] Trace mineral premix contained: 20.0% Mg, 6.0% Zn, 4.0% Mn, 5.0% Fe, 2.7% S, 1.5% Cu, .11% I, .01% Se, and .01% Co.

[‡] Vitamin premix contained: 30,000 IU/g Vitamin A, 6,000 IU/g Vitamin D, and 7.5 IU/g Vitamin E

On day four of the collection period, 45 nylon bags (15 3-bag sets) were placed in a lingerie bag in the rumen at time zero and incubated. Nylon bags (Ankom, Spencerport, NY) were 10 cm x 20 cm with a pore size of 50 μ m. Three-bag sets included two bags containing 5 g of the basal grain ground in a Wiley mill to pass a 2-mm screen and one blank bag. Sets were removed after 0, 1, 2, 3, 4, 5, 6, 9, 12, 15, 18, 21, 24, 30, and 36 h of incubation. After removal from the rumen, the bags were rinsed with cold tap water until the water ran clear, squeezed by hand to remove excess water, and dried in a forced air oven at 50°C for 72 h.

Residue in the bags was analyzed for starch, and in situ rate and extent of DM and starch disappearance were calculated (Bowman and Firkins, 1993).

Ruminal fluid was collected and pH measured at the same time that nylon bags were removed. Ruminal fluid was squeezed through 4 layers of cheese cloth and two 50-ml samples were acidified with 3 ml 6 N HCl, and frozen for later ammonia N (AOAC, 1990) and VFA (gas chromatography) analysis. Preparation for VFA analysis included treating 5 ml of ruminal fluid with 1 ml of 25% metaphosphoric acid (Iannotti et al., 1979). Upon completion of the in situ trial, ruminal fluid and particulate matter (1 l/steer) were collected and composited on a volume basis and blended in a blender for approximately 3 min. Fluid and particulate matter were twice squeezed through 4 layers of cheese cloth and ruminal bacteria were isolated by differential centrifugation (Smith and McAllen, 1974). Ruminal bacteria and composited lyophilized abomasal samples were analyzed for purine content (Zinn and Owens, 1986). The purine values were used as a microbial marker to partition N flow to the abomasum.

Data were analyzed as a 4 X 4 Latin square design using the GLM procedure of SAS (1993), with the model $y_{ijk} = \mu + \tau_i + \rho_j + \omega_k + \epsilon_{ijk}$. The overall model is represented by y_{ijk} with μ = grand mean, τ_i = the treatment effect (n=4), ρ_j = the period effect (n=4), ω_k = steer effect (n = 4), ϵ_{ijk} = the overall error effect. Treatment least squares means were separated by the LSD method (SAS, 1993) if the treatment F-test was significant ($P < .10$). Least square means and the associated standard errors are reported.

Results and Discussion

Mean DM and starch content of the diets were not different ($P > .10$) between treatments, however CP content did differ ($P = .0004$; Table 7). The HAR diet was higher in CP (11.56%; $P = .0004$) when compared with the three remaining treatments (average 13.31%). This may be related to improper mixing of the supplement for the HAR diet.

Table 7. Nutrient content of 4 x 4 Latin square diets with corn, Gunhilde barley, (GUN), Medallion barley (MED), Harrington barley (HAR) based high concentrate diets.

Item	Barley variety				SE	P > F
	Corn	GUN	MED	HAR		
..... DM basis						
Nutrient						
DM, %	87.63	88.31	88.69	88.15	.276	.2084
CP, %	13.25 ^b	13.25 ^b	13.44 ^b	11.56 ^a	.014	.0004
Starch, %	46.42	45.58	42.15	45.25	.621	.1107
NE _m , Mcal/kg [†]	1.87	1.87	1.87	1.87	--	--
NE _g , Mcal/kg [†]	1.23	1.23	1.23	1.23	--	--

[†] Calculated based on NRC (1984).

No differences ($P > .10$) were detected in DM and starch intakes (average 6109.9 and 2737.9 g/d, respectively; Table 8). Organic matter intake was higher ($P = .0668$) for the GUN and MED fed steers (average 5731.5 g/d) when compared with the corn (5653.9 g/d) fed steers. Steers consuming HAR had the lower ($P = .0004$) intake of N when compared with the remaining diets (Table 8). Dry matter intakes resembled restricted intakes presented in other barley metabolism studies (Spicer et al., 1986; Kennelly and Ha, 1990; Zinn, 1993).

Dry matter and OM flowing to the abomasum was greater ($P = .0758$ and $.0949$, respectively) for the GUN and HAR fed steers when compared with the corn fed steers. However, the intermediate, MED fed steers, did not differ when compared to the other diets (Table 8). No difference ($P = .2548$) in starch flow to the abomasum was detected. This disagrees with the hypothesis that ruminal starch digestion was different for corn and barley, and Ørskov (1986) who reported that up to 30% of the corn starch presented to the rumen could escape ruminal fermentation and be presented to the abomasum. But, our results do agree with recent research (Zinn, 1993) reporting starch flow to the duodenum for steam flaked corn and different barley processing techniques. The starch flow (Zinn, 1993) for the corn fed steers (317 g/d) was intermediate to dry rolled barley (466 g/d) and steam flaked barley (209 g/d). These results also agree with Spicer et al. (1986) who reported that there was no difference in the amount of starch entering the abomasum for corn fed steers when compared with barley fed steers. The amount of starch passing to the abomasum in this study is substantially lower than the previous reports. This may be influenced by the grain processing technique, however Zinn (1993) reported 466 g/d of starch passing to the duodenum for dry-rolled barley. The cracking employed in this study may have been more destructive, increasing the surface area, potentially increasing microbial attachment and ruminal digestion.

Table 8. In vivo nutrient intakes, fecal and abomasal output, and digestibilities by steers fed corn, Gunhilde barley (GUN), Medallion barley (MED), or Harrington barley (HAR) based diets

Item	Corn	Barley Variety			SE	Pr > F
		GUN	MED	HAR		
		% DM basis				
Intake, g/d						
DM	6068.9	6117.3	6145.3	6107.9	19.90	.2068
OM	5642.9 ^a	5761.0 ^b	5762.0 ^b	5664.8 ^{ab}	25.41	.0068
Starch	2820.6	2787.3	2583.8	2759.9	67.98	.1691
N	128.9 ^b	129.7 ^b	131.9 ^b	113.4 ^a	.84	.0004
Flow to abomasum, g/d						
DM	2583.2 ^a	3149.3 ^b	2947.8 ^{ab}	3313.0 ^b	134.92	.0758
OM	2057.7 ^a	2513.4 ^b	2394.5 ^{ab}	2626.8 ^b	112.98	.0949
Starch	237.9	195.5	136.2	189.4	30.15	.2548
Total N	88.6 ^a	107.8 ^b	94.6 ^a	114.7 ^b	3.08	.0393
Ammonia N	2.0 ^a	3.9 ^b	3.9 ^b	2.7 ^a	.38	.0682
Nonammonia N	86.6 ^a	103.9 ^b	90.7 ^a	112.0 ^b	4.38	.0437
Microbial N	58.1 ^a	83.6 ^{bc}	76.3 ^b	91.1 ^c	4.43	.0279
Feed N	28.5 ^c	20.4 ^b	14.4 ^a	20.9 ^b	1.72	.0211
Ruminal digestion, %						
DM	57.40 ^b	48.78 ^a	52.34 ^a	46.32 ^{ab}	2.117	.0805
OM	63.45	56.47	58.70	54.15	1.912	.1078
Starch	91.54	92.77	93.22	94.66	1.120	.3634
Feed N	77.98 ^a	84.03 ^b	89.62 ^c	81.30 ^{ab}	2.722	.0185
Microbial eff.	15.83 ^a	26.16 ^b	23.17 ^b	29.62 ^b	2.226	.0526
Fecal excretion, g/d						
DM	2199.6	2106.3	2114.8	2210.5	114.9	.8859
OM	1824.0	1766.6	1797.8	1846.4	99.02	.9462
Starch	160.2 ^b	45.8 ^a	33.3 ^a	31.7 ^a	27.80	.0908
N	49.1 ^b	42.4 ^a	37.8 ^a	43.0 ^a	1.79	.0660
Postruminal digestion, % [†]						
DM	16.99 ^a	32.95 ^b	28.50 ^{ab}	32.95 ^b	30.76	.0655
OM	13.50	29.43	25.02	29.30	3.732	.1180
Starch	23.80	76.80	84.87	76.10	14.453	.1326
N	45.69 ^a	60.16 ^b	58.65 ^b	62.81 ^b	1.532	.0058
Total tract digestion						
DM, g/d	3896.3	4011.0	3897.3	4030.3	104.45	.6818
DM, %	64.12	65.87	65.90	64.07	1.714	.8081
OM, g/d	3818.7	3994.3	3964.4	3818.5	75.02	.3626
OM, %	67.96	69.57	69.07	67.63	1.520	.8030
Starch, g/d	2660.4 ^{ab}	2741.5 ^b	2550.5 ^a	2728.2 ^{ab}	46.50	.0920
Starch, %	94.56 ^a	98.30 ^b	98.72 ^b	98.81 ^b	.900	.0494
N, g/d	79.8 ^b	87.3 ^c	93.2 ^a	70.3 ^d	1.62	.0092
N, %	62.40 ^a	67.39 ^a	70.64 ^b	62.56 ^a	1.18	.0075

^{a,b,c} Means in a row without a common superscript differ ($P < .05$)

[†] Postruminal digestion is calculated as a percentage of the nutrient presented to the abomasum.

Total N and nonammonia N presented to the abomasum was greater ($P < .10$) for HAR and GUN fed steers (average 111.3 and 108.0 g/d, respectively) when compared with the steers consuming MED and corn (average 91.6 and 88.7 g/d, respectively; Table 8). Nonammonia N includes endogenous and protozoal N and may be a biased estimate. Ammonia N levels were higher ($P = .0682$) for GUN and MED fed steers (average 3.9 g/d) when compared with corn and HAR (average 2.4 g/d). Steers consuming corn had the lowest ($P = .0279$) microbial N passing to the abomasum when compared with the three barley treatments. Feed N entering the abomasum was greatest for corn fed steers, intermediate for HAR and GUN fed steers and lowest for the steers consuming MED. These results agree with Spicer et al. (1986), who reported higher feed N entering the abomasum for corn fed steers. However, Zinn (1993) reported feed N presented to the duodenum for steers fed steam flaked corn to be substantially lower than levels measured in cattle fed either steam flaked or dry rolled barley. The amount of feed N presented to the abomasum in our study is similar to other metabolism studies that processed the corn by rolling (Streeter et al., 1990). It would appear dry rolled or cracked corn increased feed N passing to the duodenum compared to barley, potentially increasing essential and nonessential amino acids provided by feed N rather than microbial N. Spicer et al. (1986) reported amino acid profiles for abomasal samples to differ only slightly when comparing corn and barley based high concentrate diets. This increase in feed N flow may partially compensate for the lower microbial N flow to the duodenum in corn fed cattle. However, in barley fed cattle the majority of N was provided by the microbial N flow rather than feed N. The HAR and GUN fed cattle presented the greatest feed N and microbial N to the duodenum. However, this

increase of N (endogenous and protozoal N included) resulted in higher ($P < .05$) ADG for HAR fed cattle when compared to GUN fed cattle in a feedlot performance trial (Boss et al., 1994), although the HAR fed steers had higher ($P > .05$) DM intakes. It would appear for barley fed cattle, this increase in N flowing to the duodenum is correlated to increased animal performance. Huntington (1994) reviewed starch utilization in ruminants and reported that the additional flow of microbial protein to the small intestine, and VFA produced from rapidly fermented feedstuffs are more efficiently used than glucose absorbed in the small intestine from feeds that have higher starch bypass. In addition, glucose absorbed and oxidized above the ruminant's requirement is not utilized as efficiently as the absorption of the organic acid fermentation products. However this theory cannot, in this study, be used when evaluating corn.

Ruminal DM digestion was higher ($P = .0805$) for the corn (57.40%) fed steers when compared to MED and GUN treatments (average 50.56%; Table 8). Ruminal DM digestion for the HAR diet (46.32%) was intermediate and did not differ from corn, MED and GUN. Ruminal OM digestion did not differ between treatments. This refutes Spicer et al. (1986) who reported that the majority of the OM digestion for barley fed cattle took place in the rumen, and for corn fed cattle post-rationally. Ruminal OM digestion was below the lower ranges for other published results (Ovenell and Nelson, 1992; Ovenell et al., 1993) for barley, and for corn and barley (Zinn, 1993), but the trends in OM digestion are similar. Ruminal starch digestion did not differ ($P = .3634$) between treatments (Table 8), disagreeing with Zinn (1993) who reported that steers consuming steam flaked corn had starch digestion intermediate to dry-rolled barley and steam flaked barley (Zinn, 1993). Ruminal starch

digestion was significantly higher than other studies (corn 83.7% and 87.7%, Spicer et al., 1986; corn 83.9% and barley 84.7%, Zinn, 1993) and may be influenced by cracking rather than steam flaking the grains. Less destructive grain processing techniques have been shown to increase rumen pH stability (Kennelly and Ha, 1990) of barley fed cattle, decreasing ruminal digestion. Zinn (1993) reported dry-rolled barley had lower ruminal digestion than steam flaked barley. Effects of barley processing have varied, but most studies agree that some form of barley processing is required, and less destructive techniques that decrease rumen digestibility are preferred.

Ruminal digestion of feed N was lowest ($P = .0185$) for the corn fed cattle, higher for HAR fed steers, and highest for the steers consuming MED (Table 8). Gunhilde was intermediate and not different from corn and HAR in ruminal digestion of feed N. It would appear the N presented in the MED diet was more available for ruminal microbe digestion than the other diets. Microbial efficiencies, calculated as the g of microbial N per 1000 g OM digested in the rumen, was greater ($P = .0526$) for the steers consuming the barley treatments when compared with corn. Possibly, the barley based diets provided rapidly available energy to the microbes allowing increased growth rates and passage of microbial N into the abomasum.

No difference was detected in DM or OM fecal excretion (Table 8). The amount of fecal starch and N was 76.9 and 16.1% greater, respectively ($P = .0908$ and $.0660$) for the steers consuming corn when compared to the three barley treatments. Starch excretion agrees with Waldo (1973) and Ørskov (1986) who reported that total tract starch digestion

was more complete for barley than corn. However, Spicer et al. (1986) and Zinn (1993) reported that total tract starch digestion was not different when comparing corn and barley.

Postruminal digestion was expressed as the percentage of material disappearing from the original amount presented to the abomasum (Table 8). Postruminal DM digestion was affected by treatment. Steers consuming corn digested 48.5% less ($P = .0655$) DM postruminally than steers consuming GUN and HAR. Steers fed MED had an intermediate level of postruminal digestion and did not differ from corn or GUN and MED.

Postruminal OM and starch digestion were not found to differ between treatments ($P = .1180$ and $.1326$, respectively). Our postruminal starch digestion results are much lower than those reported by Spicer et al. (1986) and Zinn (1993). In both cases the amount of starch presented was higher than our results. It would appear that the smaller amounts of starch presented to the duodenum in our study may have been the fraction most resistant to bacterial attachment and digestion, and thus less available to pancreatic amylases. McAllister et al. (1993) reported differences in the protein matrix in which the starch granules are embedded for corn and barley. This structural difference may impact bacterial attachment and restrict amylase binding capacity thus decreasing ruminal and small intestinal digestion. They also reported that the matrix may impact digestion of corn more than barley.

Fannon et al. (1992) reported differences in starch pore location and structure and hypothesized the pores may limit access by the amylases. Nitrogen digested postruminally was 24.5% lower ($P = .0058$) for corn when compared to the three barley treatments. Combined with lower feed N presented to the small intestine for steers fed corn based diets, it would appear the feed N entering the abomasum must be more resistant to small intestine

digestion and(or) absorption when compared with the barley fed steers and thus provide less of the amino acids being absorbed in the small intestine.

Total tract DM and OM digestion was not affected ($P = .8081$ and $.8030$, respectively) by treatment (Table 8), in agreement with Spicer et al. (1986). Steers consuming corn had 4.2% lower ($P = .0494$) total tract starch digestion when compared to GUN, MED and HAR fed steers. These results agree with Waldo (1973), Ørskov (1986) and Owens et al. (1986) who reported that total tract starch digestion was greater for barley than corn. However, Zinn (1993) reported total tract digestion of steam flaked corn (98.3%) was intermediate to dry-rolled (95.0%) and steam flaked barley (98.4%). Total tract digestion (%) of N was higher ($P = .0075$) for steers fed MED when compared with the corn, GUN and HAR fed steers.

In vivo particulate kinetics as estimated by a one- and two-compartment model (Ellis et al., 1979) are presented in Table 9. A one-compartment model was used when modeling particulate flow to the abomasum and a two-compartment model when modeling particulate flow estimated by fecal analysis. This was done to simulate the extremely rapid rate of ruminal digestion associated with grains. Grovum and Williams (1973) reported that the 2 compartments represented in their passage kinetics model were the rumen and the lower gastrointestinal tract. Ellis et al. (1979) reported the 2 compartments represented in their model were a slow and fast digesting fraction of digesta within the rumen. Grain appears not to have a slow and fast fraction as in forages. Using this concept, the 1-compartment model was used to simulate the rumen when modeling particulate flow to the abomasum and a 2-compartment model was used to simulate the rumen and the lower digestive tract.

No difference was detected in rate of DM flow to the abomasum and retention time in the rumen ($P = .5848$ and $.5451$, respectively; Table 9). However, tau (the time required to measure detectable levels of marker in the abomasal samples after dosing, Yb) was 3.5 h longer ($P = .0077$) for corn when compared to GUN, MED and HAR. Dry matter flow to the abomasum (kg/d) calculated by the dose of Yb was 31.7% higher ($P = .0017$) for steers consuming GUN when compared with steers consuming corn, and 22.5% higher when compared with MED and HAR. The corn fed steers had an 18.8% lower abomasal DM output when compared with MED and HAR fed steers. The DM flow to the abomasum values calculated from the Yb analysis are higher than those reported for Cr_2O_3 , but follow the trend for the barley fed steers to have a greater DM output than for the corn fed steers.

Table 9. In vivo digestion kinetics for steers fed corn, Gunhilde barley (GUN), Medallion barley (MED), or Harrington barley (HAR) based diets (Ellis et al., 1979)

Item	Corn	Barley Variety			SE	Pr > F
		GUN	MED	HAR		
Abomasal, 1 compartment model						
Tau, h	6.64 ^c	2.44 ^a	3.71 ^b	3.19 ^{ab}	.445	.0077
Flow rate, h ⁻¹	.049	.049	.046	.054	.0045	.5845
Retention time, h	31.6	27.2	30.1	25.8	1.86	.2451
DM output,kg/d	4.21 ^a	6.70 ^c	5.00 ^b	5.37 ^b	.196	.0017
Fecal, 2 compartment model						
Tau, h	14.0 ^c	7.6 ^a	10.7 ^b	10.5 ^b	.77	.0156
Flow rate, h ⁻¹	.047	.062	.037	.053	.0069	.1796
Retention time, h	46.5 ^b	36.1 ^a	47.4 ^b	39.0 ^a	2.04	.0244
DM output, kg/d	1.74 ^a	2.56 ^c	1.77 ^a	2.05 ^b	.050	.0013

^{a,b,c} Means in a row without a common superscript differ ($P < .05$).

In vivo digestion kinetics modeling particulate flow calculated from the fecal analysis is presented in Table 9. No difference ($P = .1796$) was detected in total tract particulate flow rate of the four diets (average $.050 \text{ h}^{-1}$; Table 9). However, corn and MED had longer ($P = .0244$) retention times (average 47.0 h) when compared with GUN and HAR (average 37.6 h). Corn had a 32% longer ($P = .0156$) tau (14.0 h) than MED and HAR (average 10.6 h), while tau for GUN was 28% shorter ($P = .0156$) than for MED and HAR. The fecal outputs calculated from the Yb-dose agree with the values calculated from the Cr_2O_3 marker analysis. It would appear that Yb-marked grain may be as good a marker for estimating fecal output as Cr_2O_3 . It would appear from data variation, caused by some limitation with either marker, that the use of a single marker rather than the dual marker technique is not suggested at this time.

In situ DM disappearance for the basal grains is presented in Figure 2. No differences were detected in DM disappearance between treatments at 0 and 1 h of incubation. The DM disappearance of corn was lower ($P < .05$) than the three barleys at all times except 15 and 30 h. At 15 and again at 30 h of incubation DM disappearance for corn and MED was lower ($P < .05$) when compared with HAR and GUN, however at 15 h the MED did not differ from the GUN and HAR. The disappearance of HAR at 2 and 3 h of incubation was greater ($P < .05$) when compared to MED, however GUN did not differ from either MED or HAR at these times. From 4 to 9 h of incubation no difference was detected in barley DM disappearance, but the barleys all had greater ($P < .05$) DM disappearance when compared with corn. After 12 h of incubation DM disappearance of corn was lowest ($P = .0164$) followed by MED and GUN, although the GUN did not differ from HAR, which had the

highest DM disappearance. At 18 and 21 h of incubation corn had the lowest ($P < .05$) DM disappearance, MED had an intermediate DM disappearance, and the highest DM disappearance was seen in the HAR and GUN grains. At 24 h of incubation no difference in DM disappearance was detected between the three barleys, but all were higher ($P = .0412$) than corn. At 36 h of incubation DM disappearance was highest ($P = .0046$) for GUN (91.59%), intermediate for HAR and MED (89.75 and 86.67%, respectively), and lowest for corn (80.08%). The rate of DM disappearance was 83% slower ($P < .0940$) for corn ($.0538 \text{ h}^{-1}$) compared with HAR and GUN ($.2778$ and $.3723 \text{ h}^{-1}$), although no difference was detected between the intermediate, MED ($.2241 \text{ h}^{-1}$) and the other treatments (Table 10). These results agree with Ørskov (1986) who reported faster and more complete digestion of barley by cattle compared with corn, and are similar to results presented by Herrera-Saldana et al. (1990).

Table 10. In situ DM and starch disappearance of corn, Gunhilde barley (GUN), Medallion barley (MED), or Harrington barley (HAR).

Item	Corn	Barley Variety			SE	Pr > F
		GUN	MED	HAR		
Extent of disappearance, % [†]						
DM	82.15 ^a	91.59 ^c	86.67 ^b	89.75 ^c	.445	.0077
Starch	70.30 ^a	95.95 ^b	99.39 ^b	99.03 ^b	3.920	.0052
Rate of disappearance, h ⁻¹						
DM	-.0538 ^a	-.2778 ^b	-.3723 ^b	-.2241 ^{ab}	.07243	.0940
Starch	-.1139 ^a	-.3602 ^b	-.4986 ^b	-.5593 ^b	.07441	.0319

^{a,b,c} Means in a row without a common superscript differ ($P < .05$).

[†] DM disappearance at 36 h of in situ incubation.

Starch disappearance at 15 h of in situ incubation.

In situ starch disappearance is presented in Figure 3. Starch disappearance of corn was lower ($P < .05$) at all times between 0 and 15 h compared with the three barleys. No difference ($P > .05$) was seen in starch digestion between GUN, HAR and MED at 0 and 1 h. By 2 h of incubation HAR had 7.6% greater ($P = .0001$) starch disappearance compared with GUN, and MED was intermediate and did not differ from either GUN or HAR. Gunhilde had a lower ($P < .05$) starch disappearance at 3, 4 and 5 h than MED or HAR. No differences ($P > .05$) in starch digestion were found for GUN, HAR and MED at 6, 12 and 15 h of incubation. The rate of starch disappearance was 315% faster ($P = .0319$) for MED ($.5593 \text{ h}^{-1}$), HAR ($.4986 \text{ h}^{-1}$) and GUN ($.3602 \text{ h}^{-1}$) when compared with corn ($.1139 \text{ h}^{-1}$; Table 10).

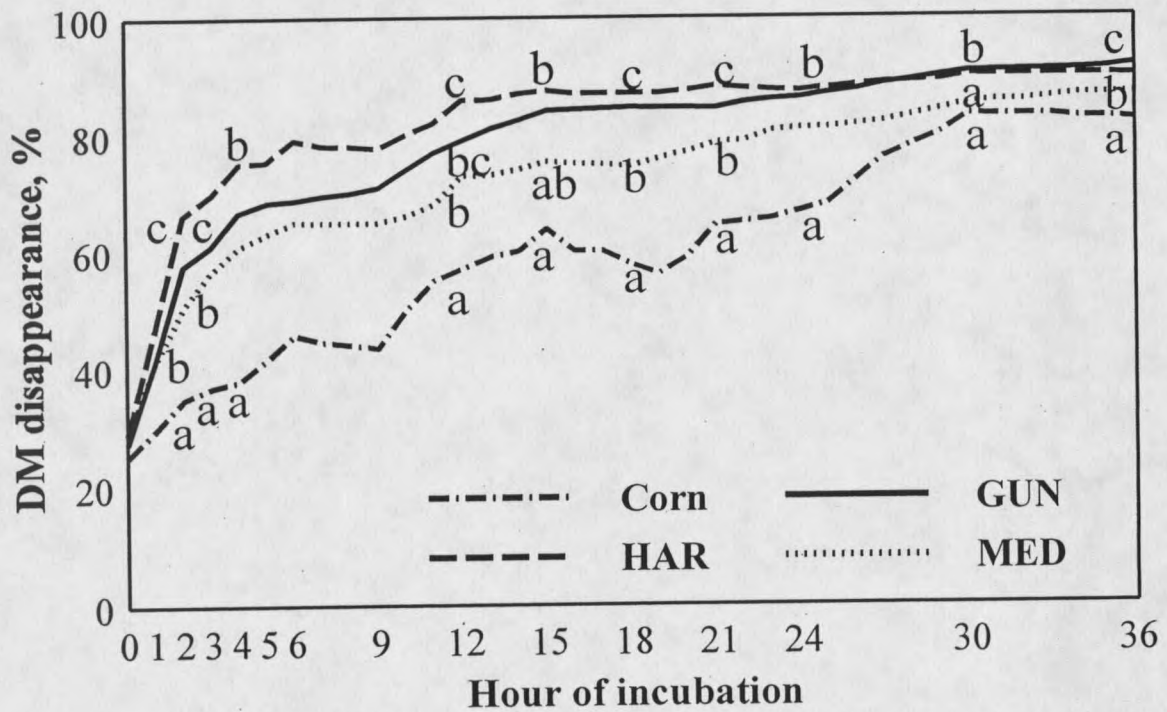


Figure 2. In situ DM digestion of corn, Gunhilde barley (GUN), Medallion barley (MED), or Harrington barley (HAR). Hours without common superscripts differ ($P < .05$).

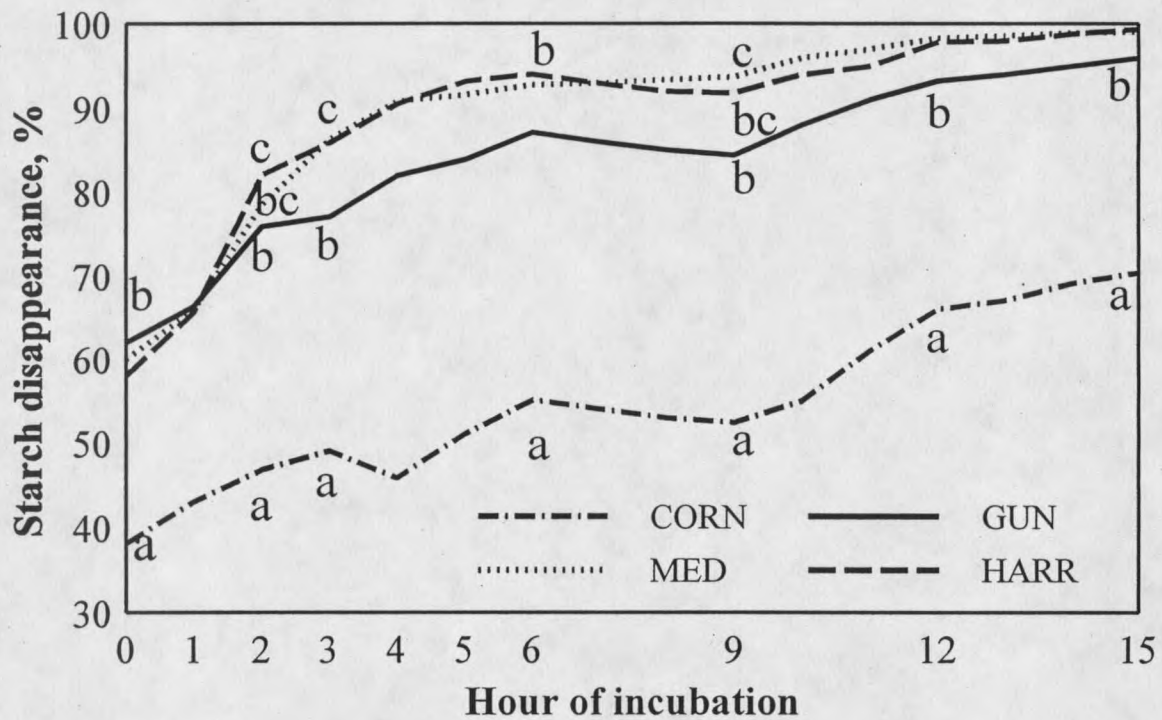


Figure 3. In situ starch disappearance of corn, Gunhilde barley (GUN), Medallion barley (MED) or Harrington barley (HARR). Hours without common superscripts differ ($P < .05$).

No differences ($P > .10$) in ruminal pH (Figure 4) were detected until 9 h after the initial 0600 feeding. At 9 and 12 h, and again at 30 and 36 h, steers fed corn had higher ($P < .10$) ruminal pH than those fed GUN, HAR or MED. Lower ruminal pH measured in steers consuming GUN, HAR and MED may be related to lower ($P < .10$) DM intakes by steers fed the same barley diets (offered ad libitum) compared with steers fed corn in an associated finishing experiment.

Ruminal ammonia concentrations are presented in Figure 5. Steers fed corn and HAR had lower ($P = .0262$) ruminal ammonia levels (average 4.52 mg/dl) at 9 h after the 0600 feeding compared with steers fed MED and GUN (average 7.59 mg/dl). Ruminal ammonia in steers consuming corn remained lower ($P = .0001$) at 12 h, compared with steers fed the barley diets. Steers consuming corn and MED had higher (average 10.57 mg/dl; $P = .0033$) ammonia levels at 15 h post feeding when compared with steers consuming GUN and HAR. Ruminal ammonia levels appeared to be highest at feeding, decline until 6 h after feeding, and then rise again. Satter and Slyter (1974) reported that rumen ammonia levels above 5 mg/dl supported maximum growth rates of rumen bacteria. Ruminal ammonia levels in this study ranged between 4.5 and 11.5 mg/dl, and therefore it appears rumen ammonia was not limiting bacterial growth.

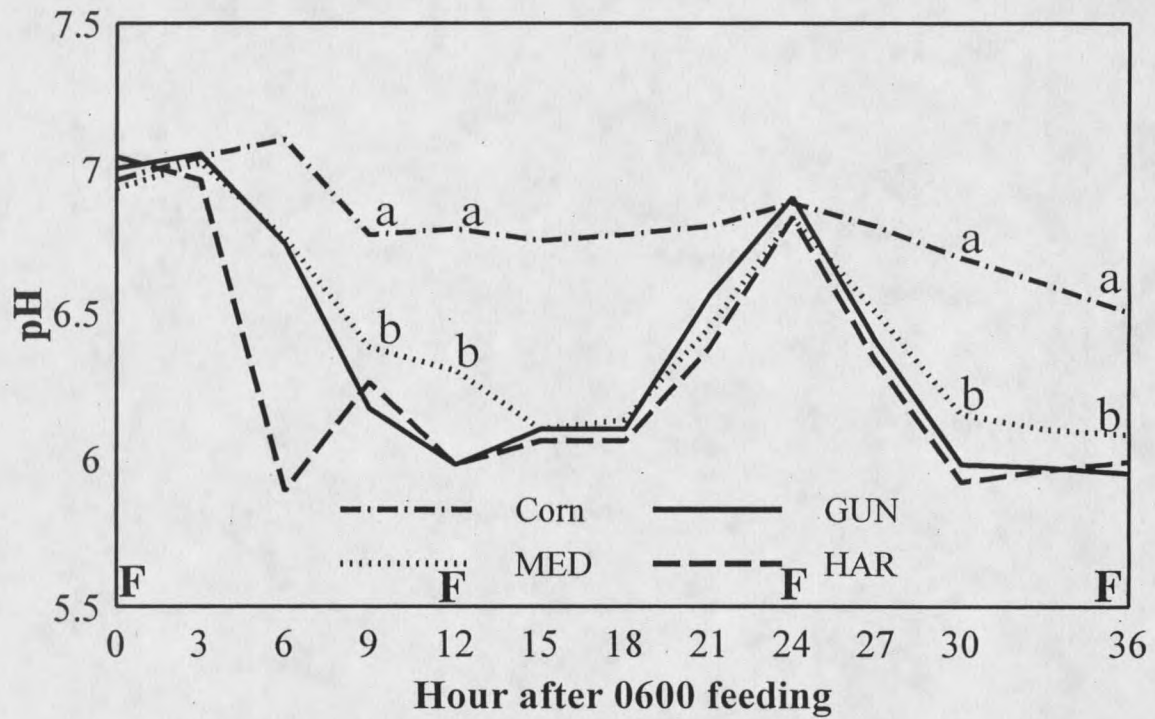


Figure 4. Ruminal fluid pH of steers fed corn, Gunhilde barley (GUN), Medallion barley (MED), or Harrington barley (HAR) based high concentrate diets. Hour represents hours after 0600 feeding (time = 0). "F" represents time the steers were fed. Hours without common superscripts differ ($P < .05$).

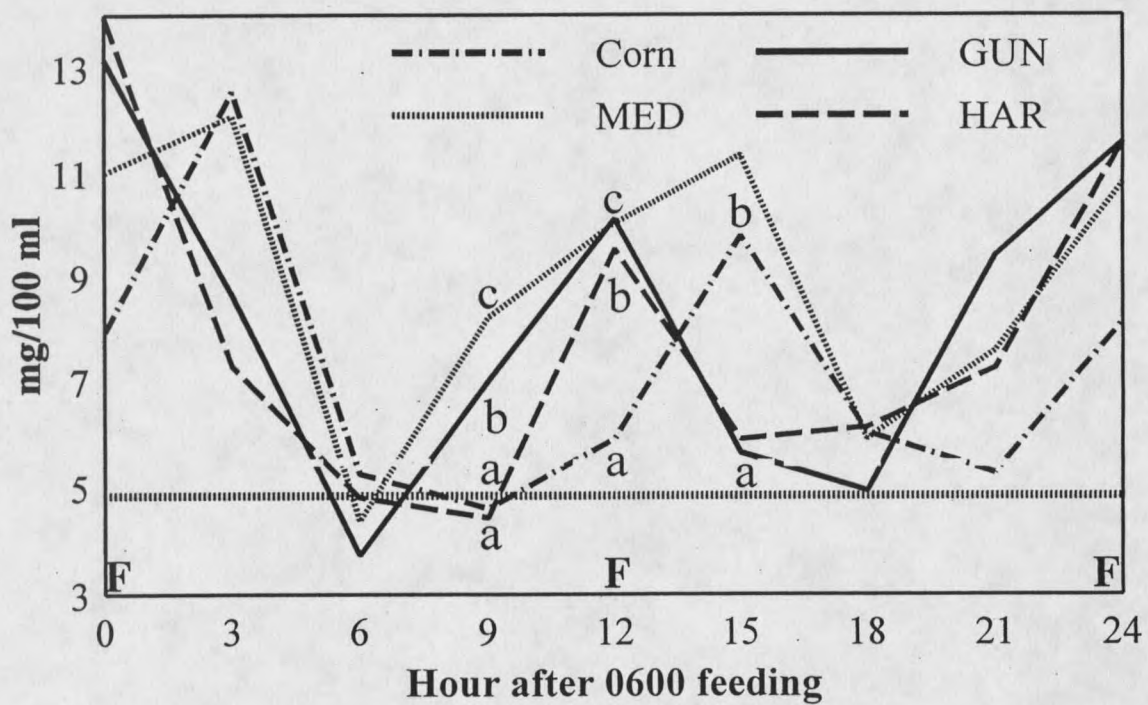


Figure 5. Ruminal fluid ammonia concentrations of steers fed corn, Gunhilde barley (GUN), Medallion barley (MED), or Harrington barley (HAR) based high concentrate diets. Hour is based on hours after 0600 feeding (time = 0). Horizontal line at 5 mg/dl represents Satter and Slyter (1974) lower level of ruminal fluid ammonia concentrations to maintain maximal ruminal bacterial growth rates. "F" represents the time the steers were fed. Hours without common superscripts differ ($P < .05$).

No difference ($P > .10$) in ruminal fluid VFA concentration was detected from feeding to 15 h post 0600 feeding (Table 10). However, 18 h VFA concentration was lowest ($P = .0280$) for steers consuming corn, intermediate for steers consuming MED and GUN, and highest for steers consuming HAR. Ruminal fluid VFA concentration for HAR fed steers did not differ from the GUN fed steers. Differences in specific VFA as a percentage of total VFA were limited and are presented in Table 11. No difference in percentage branch chain VFA was detected over the collection period. No difference was detected in acetate to propionate ratios except at 21 h post feeding. The corn fed steers 21 h post feeding had a lower ($P = .0469$) ratio (1.38) than any of the barley treatments (average 1.88).

Table 11. Ruminal fluid VFA concentration by hour after feeding for steers fed corn, Gunhilde barley (GUN), Medallion barley (MED), or Harrington barley (HAR) based diets.

Hour	Barley Variety				SE	Pr > F
VFA, % [†]	Corn	GUN	MED	HAR		
Feeding						
Total, mol	5.91	5.44	5.83	6.07	.171	.1489
Formic	7.18 ^a	7.45 ^a	8.08 ^b	7.45 ^a	.164	.0510
Acetic	50.50 ^a	53.93 ^c	52.75 ^{bc}	52.03 ^{ab}	.495	.0274
Propionic	19.86	17.28	16.38	17.43	1.093	.3234
Isobutyric	1.63	1.70	1.58	1.50	.072	.3106
Butyric	16.22	14.63	16.55	17.03	.899	.2746
Isovaleric	3.19	3.45	3.15	3.03	.311	.7732
Valeric	1.42	1.60	1.48	1.58	.112	.6762
Branch chain	4.81	5.13	4.78	4.53	.365	.6848
Ac:Pr, ratio	2.59	3.20	3.20	3.08	.196	.2805
3 hour						
Total, mol	7.28	8.54	8.22	8.70	.534	.4139
Formic	5.88 ^a	7.03 ^b	6.48 ^{ab}	6.10 ^a	.221	.0564
Acetic	50.75	52.08	51.15	49.98	.861	.4076
Propionic	22.17	22.10	21.68	22.03	1.458	.9959
Isobutyric	1.35 ^b	1.15 ^a	1.15 ^a	1.10 ^a	.038	.0334
Butyric	15.83	12.68	14.80	16.28	.970	.1347
Isovaleric	2.54	2.83	2.60	2.60	.287	.8928
Valeric	1.57	2.18	2.15	1.93	.147	.1299
Ac:Pr, ratio	2.36	2.42	2.38	2.33	.187	.9803

Table 11. Continued.

Hour		Barley Variety				
	VFA, % [†]	Corn	GUN	MED	HAR	SE
						Pr > F
6 hour						
Total, mol	7.35	11.13	8.69	9.12	1.038	.2131
Formic	5.83	6.20	6.20	5.75	.332	.6694
Acetic	50.00	52.13	49.65	49.33	.817	.1533
Propionic	18.83	15.88	22.55	23.08	3.636	.4739
Isobutyric	1.44 ^b	1.20 ^a	1.10 ^a	1.03 ^a	.069	.0457
Butyric	17.53 ^b	12.95 ^a	15.10 ^{ab}	16.55 ^b	.939	.0721
Isovaleric	2.73	3.23	2.88	2.83	.340	.6233
Valeric	1.57	2.13	2.00	1.98	.180	.3355
Branch chain	1.19	4.40	3.98	3.85	.361	.6921
Acetic:propionic	2.46	2.43	2.18	2.28	.163	.6134
9 hour						
Total, mol	6.33	6.99	7.79	7.16	3.431	.1520
Formic	5.08	5.93	6.03	6.48	.539	.4727
Acetic	50.29	52.80	51.90	49.83	1.201	.3372
Propionic	21.31	20.38	19.25	20.70	1.504	.8125
Isobutyric	1.56	1.43	13.0	1.20	.083	.1218
Butyric	17.38	14.33	16.60	16.95	1.085	.2908
Isovaleric	2.86	3.15	3.08	3.05	.288	.9242
Valeric	1.54	1.95	1.85	1.83	.157	.4645
Branch chain	4.43	4.58	4.40	4.23	.304	.8537
Acetic:propionic	2.43	2.68	2.70	2.50	.223	.8000
12 hour						
Total, mol	5.26	5.26	5.59	5.66	.300	.6894
Formic	4.65	5.65	5.83	5.43	.402	.3618
Acetic	51.15	53.85	52.95	51.35	1.075	.3287
Propionic	20.24	18.45	17.05	18.63	1.204	.4526
Isobutyric	1.82 ^b	1.75 ^b	1.58 ^a	1.48 ^a	.065	.0460
Butyric	17.36	15.15	17.63	18.10	1.141	.3218
Isovaleric	3.34	3.38	3.28	3.33	.271	.9933
Valeric	1.47	1.80	1.70	1.70	.108	.3493
Branch chain	5.20	5.13	4.90	4.78	.325	.7866
Ac:Pr	2.62	3.00	3.10	2.85	.223	.5612
15 hour						
Total, mol	6.85	8.05	8.24	8.84	.554	.2512
Formic	4.27	4.35	4.75	3.80	.312	.2649
Acetic	49.33 ^{ab}	52.35 ^b	51.38 ^b	46.78 ^a	1.261	.0732
Propionic	22.88	24.10	23.23	25.20	1.382	.6625
Isobutyric	1.32	1.13	1.05	1.08	.079	.2547
Butyric	17.77	12.93	14.73	17.90	1.609	.1864
Isovaleric	2.65	2.83	2.65	3.13	.329	.7155
Valeric	1.76	2.28	2.23	2.18	.165	.3001
Branch chain	3.98	3.98	3.70	4.15	.378	.8389
Ac:Pr, ratio	2.19	2.28	2.23	1.88	.121	.1684

Table 11. Continued.

Hour	VFA, % [†]	Barley Variety			SE	Pr > F
	Corn	GUN	MED	HAR		
18 hour						
Total, mol	7.74 ^a	9.20 ^{bc}	8.86 ^{ab}	9.77 ^c	.305	.0280
Formic	6.59	7.18	7.15	6.70	.177	.1467
Acetic	49.00	51.03	50.30	48.20	.858	.1816
Propionic	22.82	23.13	21.73	22.30	1.988	.9534
Isobutyric	1.27	1.10	1.10	1.10	.069	.4269
Butyric	16.44	14.48	14.80	16.35	1.153	.1547
Isovaleric	2.35	2.98	2.98	3.40	.257	.1737
Valeric	1.56	2.05	1.95	1.95	.140	.2502
Branch chain	3.64	4.07	4.08	4.53	.262	.2807
Ac:Pr, ratio	2.24	2.40	2.35	2.33	.209	.9653
21 hour						
Total, mol	6.95	7.21	6.66	7.85	.366	.2123
Formic	6.77	6.83	7.48	6.70	.283	.2671
Acetic	49.88	52.38	48.70	48.90	2.331	.6407
Propionic	21.61	19.30	21.60	21.58	3.126	.9260
Isobutyric	1.53	1.43	1.28	1.18	.079	.1023
Butyric	16.12	14.78	16.03	16.25	1.376	.8415
Isovaleric	2.72	3.28	3.08	3.55	.296	.3882
Valeric	1.38 ^a	2.00 ^b	1.85 ^b	1.78 ^b	.102	.0469
Branch chain	4.25	4.70	4.75	4.35	.288	.5788
Ac:Pr, ratio	2.22	3.25	2.40	2.35	.566	.5750
24 hour						
Total, mol	5.60	6.09	5.88	6.48	.335	.4112
Formic	6.17	6.48	6.48	6.40	.282	.8839
Acetic	52.76	53.10	52.02	50.30	1.222	.4170
Propionic	20.53	18.85	17.60	19.20	1.294	.5557
Isobutyric	1.73	1.80	1.63	1.55	.076	.1900
Butyric	14.02 ^a	14.58 ^a	17.33 ^b	16.88 ^b	.828	.0914
Isovaleric	3.18	3.40	3.38	3.78	.279	.5577
Valeric	1.49 ^a	1.85 ^b	1.58 ^a	1.90 ^b	.088	.0563
Branch chain	4.92	5.20	5.00	5.35	.315	.7747
Ac:Pr, ratio	2.60	2.95	2.98	2.73	.215	.6159

[†] Calculated as percent of the total VFA concentration

^{abc} Means in a rows without common superscripts differ (P < .05)

Implications

Kinetics of particulate passage and ruminal digestion of high concentrate diets fed to steers were shown to differ when different barley varieties and corn were used as basal grains. Total tract starch digestibility was greater for steers consuming Harrington, Gunhilde or Medallion barleys compared with those fed corn. Intake of digestible starch was 8.2% greater for steers fed diets based on Gunhilde and Harrington barleys, compared with steers consuming Medallion barley. Ruminal retention time was greater for diets based on corn or Medallion barley compared with diets based on Gunhilde or Harrington barley. In addition, all barleys were similar and had an extremely rapid rate of ruminal DM and starch in situ disappearance rate when compared to corn. However, it would appear that some barley varieties, in this research HAR, can compensate for this rapid rate of digestion by supplying additional N in the form of microbial N to the duodenum for digestion and absorption. These results support the theory proposed by Huntington (1994) that steers consuming high concentrate diets may actually benefit more from the additional N flowing to the duodenum than starch that bypasses ruminal digestion. The glucose resulting from starch that does bypass ruminal digestion is used primarily for the tissue requirements of the viscera and organs and no large net increase in glucose can be detected. This study indicates that rapid rumen fermentation of barley may not necessarily result in depressed animal performance. It is evident that additional research is required before recommendations on the best barley variety to feed cattle can be given. It is encouraging though to begin to understand some factors that may affect the digestion kinetics associated with barley variety in high concentrate diets.

CHAPTER 5

CONCLUSIONS

Barley variety did impact feedlot performance in this study. Despite an extremely rapid rate of ruminal digestion, Harrington barley resulted in superior feedlot growth performance and carcass characteristics when compared with Medallion and Gunhilde barleys. It should be noted that performance was confounded by DM intakes, digestible DM intakes and digestible starch intakes, with corn fed steers having the highest ADG. However, it would appear that Harrington barley, which had superior quality grade and feed conversion, may be an acceptable substitute for corn in this region until the cost of corn is lower. In future research, added attention should be made to insure closer intakes to better compare barley variety to corn and its applicability to finishing steers on high concentrate diets. These data suggest that rapid ruminal digestion having a negative influence on animal performance may not be true. More research is needed to quantify and evaluate barley characteristics that influence animal performance.

Kinetics of particulate passage and ruminal digestion of high concentrate diets fed to steers were shown to differ when different barley varieties and corn were used as basal grains. Total tract starch digestibility was greater for steers consuming Harrington, Gunhilde or Medallion barleys compared with those fed corn. Intake of digestible starch was 8.2% greater for steers fed diets based on Gunhilde and Harrington barleys, compared with steers consuming Medallion barley. Ruminal retention time was greater for diets based on corn or Medallion barley compared with diets based on Gunhilde or Harrington barley. In addition,

all barleys were similar and had an extremely rapid rate of ruminal DM and starch in situ disappearance rate when compared to corn. However, it would appear that some barley varieties in this research HAR, can compensate for this rapid rate of digestion by supplying additional N in the form of microbial N to the duodenum for digestion and absorption. These results support the theory proposed by Huntington (1994) that steers consuming high concentrate diets may actually benefit more from the additional N flowing to the duodenum than starch that bypasses ruminal digestion. The glucose resulting from starch that does bypass ruminal digestion is used primarily for the tissue requirements of the viscera and organs and no large net increase in glucose can be detected. This study indicates that rapid rumen fermentation of barley may not necessarily result in depressed animal performance. It is evident that additional research is required before recommendations on the best barley variety to feed cattle can be given. It is encouraging though to begin to understand some factors that may affect the digestion kinetics associated with barley variety in high concentrate diets.

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APPENDIX

Table 12. Composition of corn, Gunhilde barley (GUN), Medallion barley (MED), and Harrington barley (HAR) grains.

Nutrient	Corn	Barley		
		GUN	MED	HAR
..... DM Basis				
Weight,kg/hl	72.1	64.5	61.7	63.1
DM,%	92.2	94.2	95.1	94.4
OM,%	90.9	91.8	92.8	92.9
ASH,%	1.5	2.7	2.6	2.7
GE,Mcal/kg	4.31	4.25	4.27	4.24
CP,%	8.7	11.1	10.6	10.7
ADF,%	4.5	6.4	6.3	6.9
Calcium,%	.00	.01	.01	0.01
Phosphorus,%	.26	.39	.38	.38
Starch, %	65.0	47.7	44.3	50.0

Table 13. Composition of corn, Gunhilde barley (GUN), Medallion barley (MED), and Harrington barley (HAR) supplements.

Harrington barley (HAR) supplements				
Nutrient	Corn	GUN	Barley	
			MED	HAR
DM Basis				
DM,%	90.7	91.4	90.6	92.8
OM,%	78.3	72.1	74.5	65.5
ASH,%	31.9	37.2	35.9	42.2
GE,Mcal/kg	2.97	2.65	2.71	2.40
CP,%	52.1	42.9	56.0	19.4
ADF,%	6.7	7.1	7.3	6.9
Calcium,%	4.79	4.91	5.14	6.50
Phosphorus,%	2.76	2.23	1.41	3.06
Starch, %	4.3	6.0	4.5	5.4

Table 14. Feedlot performance of steers fed corn, Gunhilde barley (GUN), Medallion barley (MED), or Harrington barley (HAR) based high concentrate diets by periods.

Item	Barley variety				SE	P > F
	Corn	GUN	MED	HAR		
Adaptation						
DM intake, kg	7.97	6.82	6.99	6.94	.297	.06
ADG, kg/d	.94 ^b	.68 ^a	.71 ^a	.75 ^a	.060	.04
Feed:Gain	--	--	--	--	--	--
0 to 28 d						
DM intake, kg	9.39 ^c	6.65 ^{ab}	6.29 ^a	7.34 ^b	.301	.0001
ADG, kg/d	1.21 ^b	.89 ^a	.92 ^a	1.12 ^a	.083	.05
Feed:Gain	7.96	7.57	6.88	6.72	.587	.43
28 to 56 d						
DM intake, kg	9.28 ^c	6.86 ^{ab}	6.51 ^a	7.58 ^b	.263	.0001
ADG, kg/d	1.56	1.27	1.17	1.50	.104	.07
Feed:Gain	6.07	5.50	5.54	5.10	.347	.31
56 to 84 d						
DM intake, kg	9.49 ^c	6.81 ^a	6.44 ^a	7.78 ^b	.289	.0001
ADG, kg/d	1.52 ^c	1.18 ^a	1.17 ^a	1.38 ^b	.064	.005
Feed:Gain	6.28	5.77	5.51	5.63	.198	.08
84 to 112 d						
DM intake, kg	9.84 ^c	7.26 ^{ab}	6.75 ^a	8.12 ^b	.347	.0002
ADG, kg/d	1.53 ^c	1.23 ^a	1.26 ^{ab}	1.42 ^{bc}	.058	.01
Feed:Gain	6.47	5.88	5.38	5.76	.252	.06
112 to 140 d						
DM intake, kg	9.97 ^c	7.49 ^{ab}	7.14 ^a	8.22 ^b	.313	.0002
ADG, kg/d	1.48 ^c	1.17 ^a	1.30 ^{ab}	1.35 ^{bc}	.049	.007
Feed:Gain	6.76 ^b	6.36 ^b	5.50 ^a	6.11 ^{ab}	.222	.01
140 to 168 d						
DM intake, kg	10.02 ^b	7.71 ^a	7.32 ^a	8.21 ^a	.316	.0003
ADG, kg/d	1.42 ^c	1.18 ^a	1.22 ^{ab}	1.30 ^b	.089	.004
Feed:Gain	7.05 ^b	6.55 ^{ab}	5.99 ^a	6.33 ^a	.255	.07

Table 15. Nutrient digestibilities by period early (56 d), middle (84 d) and late (140 d) by steers fed corn, Gunhilde barley (GUN), Medallion barley (MED), or Harrington barley based high concentrate diets.

Nutrient ^c	Corn	Barley			SE	Trt ^a P > F	Interaction T * P
		GUN	MED	HAR			
Early							
DM dig.,%	68.9	81.5	80.4	76.9	1.53	.0001	.70
CP dig.,%	67.5	82.0	77.9	76.4	2.09	.0001	.76
Starch, %	90.9	98.6	99.4	99.0	.99	.0001	.21
Dig. DM Int.,kg	6.7	5.6	5.2	5.8	.27	.0001	.91
Dig. Cp Int.,kg	.8	.7	.7	.6	.04	.0001	.77
Dig. Starch Int.,kg	4.1	2.6	2.3	3.0	.13	.0001	.74
Middle							
DM dig.,%	71.9	81.8	81.3	80.0	1.53	.0001	.70
CP dig.,%	68.5	79.8	74.8	79.6	2.08	.0001	.76
Starch, %	91.8	99.3	99.4	99.2	.99	.0001	.21
Dig. DM Int.,kg	7.1	5.8	5.5	6.6	.27	.0001	.91
Dig. Cp Int.,kg	.9	.7	.7	.7	.04	.0001	.77
Dig. Starch Int.,kg	4.2	2.7	2.4	3.3	.13	.0001	.74
Late							
DM dig.,%	72.0	79.5	80.7	79.9	1.53	.0001	.70
CP dig.,%	67.6	78.8	74.8	78.2	2.08	.0001	.76
Starch, %	85.5	95.1	98.0	97.4	.99	.0001	.21
Dig. DM Int.,kg	8.0	6.9	6.9	7.4	.27	.0001	.91
Dig. Cp Int.,kg	1.0	.9	.9	.8	.04	.0001	.77
Dig. Starch Int.,kg	4.4	3.2	3.0	3.7	.13	.0001	.74

^a Treatment main effects presented in text.

Table 16. Least square means analysis of variance for diet digestibility for steers fed corn, Gunhilde barley (GUN), Medallion barley(MED), or Harrington barley(HAR) based high concentrate diets.

Item	df	Sum of square	Mean square	F	P > F
Treatment	3	805.5	268.5	28.5	.0001
Period	2	26.9	13.5	1.43	.2532
TRT*Per	6	36.0	6.0	.64	.6994
Error	36	339.2	9.4	--	--
Total	47	1207	--	--	--

Table 17. Least square means analysis of variance for ADG for 168 d for steers fed corn, Gunhilde barley (GUN), Medallion barley(MED), or Harrington barley (HAR) based high concentrate diets.

Item	df	Sum of square	Mean square	F	P > F
Treatment	3	.677	.226	7.81	.0037
Error	12	.35	.03	--	--
Total	15	1.02	--	--	--

Table 18. Least square means analysis of variance for acetate to propionate ratio (0 hour) for steers fed corn, Gunhilde barley (GUN), Medallion barley (MED), and Harrington barley (HAR) based high concentrate diets.

Item	df	Sum of square	Mean square	F	P > F
TYPE I					
Steer	3	.825	.275	2.06	.2246
Period	3	.852	.284	2.12	.2157
Treatment	3	.684	.228	1.71	.2805
TYPE II					
Steer	3	.301	.100	.75	.5677
Period	3	1.261	.420	3.14	.1247
Treatment	3	.684	.228	1.71	.2805
Error	5	.668	.134	--	--
Total	14	3.029	--	--	--

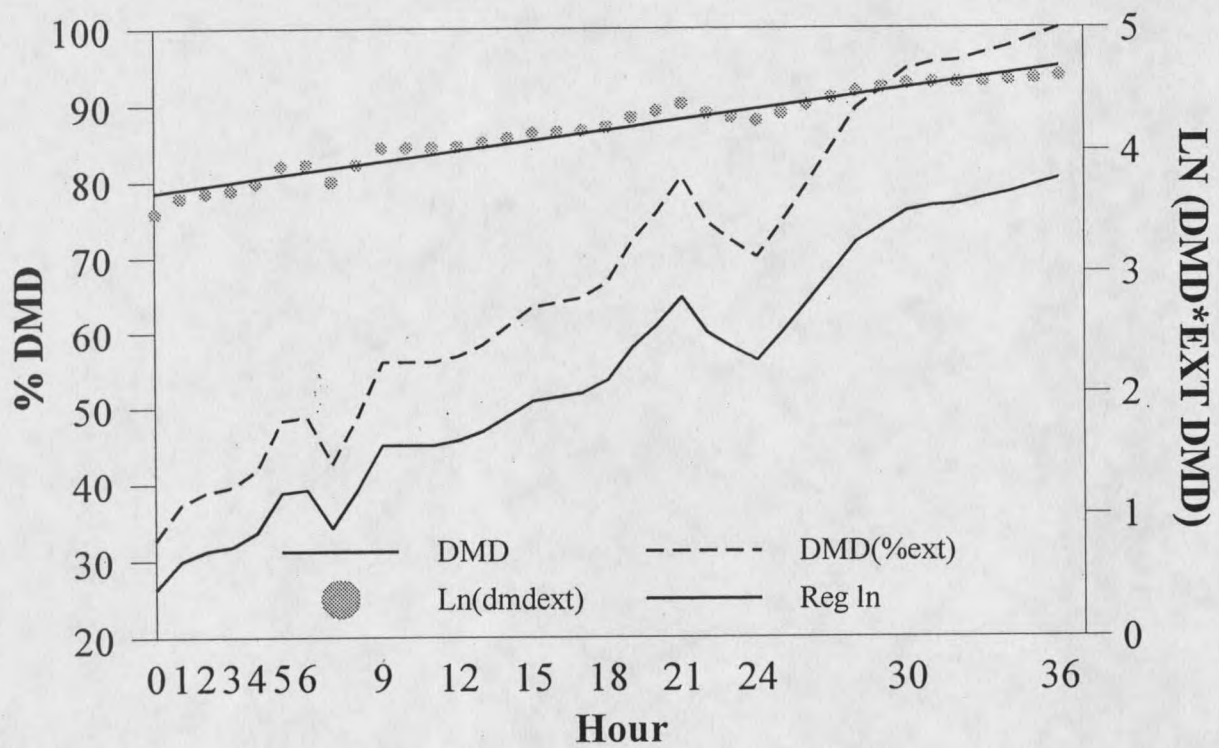


Figure 6. Calculation of DM and starch rate of disappearance.

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