



Influence of starch digestion rate on feedlot performance and site of starch digestion in beef steers fed high concentrate diets of corn or barley
by Thomas James Milner

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

Two trials were conducted to determine the effects of high concentrate diets of corn or barley. Diets were corn (control); Gunhilde barley (GUN); Harrington barley (HAR); and 50% Gunhilde + 50% Harrington (MIX). Trial one evaluated feedlot performance and carcass characteristics of beef steers fed corn or barley. Eighty crossbred steers were utilized in a randomized complete block design. Trial two examined ruminal digestion of steers fed high concentrate diets of corn or barley. Four ruminally and duodenally cannulated steers were used in a 4 X 4 Latin square designed metabolism trial. Corn-fed steers gained 7% faster ($P = .04$) than barley-fed steers. No other differences ($P > .10$) in animal performance were seen when barleys were compared. Dry matter intake for corn-fed steers was higher ($P = .0002$) yet feed efficiency was not different ($P > .05$) between diets. Harrington had greater ($P = .01$) total starch and digestible starch intake than GUN. Gunhilde had greater ($P = .01$) DMD than HAR-fed steers. Corn-fed steers had greater ($P < .10$) hot carcass and kidney/heart/pelvic fat% than barley-fed steers. Feed cost and cost of gain for barley rations was lower ($P = .002$) than corn rations. Starch flow to the duodenum was greater ($P = .004$) for corn-fed diets. Total tract starch digestion, along with DM and N, were greater ($P = .03$) for barley-fed steers. No associative effects ($P > .10$) were seen in nutrient flow to the duodenum or ruminal digestion (%) when MIX was compared to GUN/HAR. GUN had greater ($P = .003$) retention time and lower ($P = .007$) flow rate than HAR-fed steers. Corn-fed steers had greater ($P < .05$) animal performance when compared to steers fed barley. With feed efficiencies similar ($P > .05$), lower feed cost of barley based diets make them an attractive alternative to corn in the Northern Great Plains and Pacific Northwest region. We observed similar animal performance and metabolic traits of GUN and HAR in these trials. This trial reaffirms the need for research into environmental and growing location that affect feeding values of barley.

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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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TABLE OF CONTENTS

LIST OF TABLES.....	vi
LIST OF FIGURES	vii
ABSTRACT.....	viii
1. INTRODUCTION	1
2. LITERATURE REVIEW	4
Grain Processing	4
Digestive Disorders.....	7
Starch Structure and Function	12
Ruminal Starch Utilization.....	15
3. FEEDLOT PERFORMANCE AND CARCASS CHARACTERISTICS OF BEEF STEERS FED CORN OR BARLEY	21
Introduction	21
Materials and Methods.....	22
Results and Discussion.....	26
Implications.....	32
4. RUMINAL DIGESTION BY STEERS FED HIGH CONCENTRATE DIETS CONTAINING CORN OR BARLEY	34
Introduction	34
Materials and Methods.....	35
Results and Discussion.....	39
Implications.....	52
5. CONCLUSION.....	53
LITERATURE CITED.....	55
APPENDIX A - ANALYSIS OF VARIANCE TABLES.....	62

LIST OF TABLES

Table	Page
1. Composition (% DM basis) of finishing diets containing corn, Gunhilde barley (GUN), Harrington barley (HAR), or 50% Gunhilde + 50% Harrington (MIX) as basal grains.....	24
2. Performance by steers consuming finishing diets containing corn, Gunhilde barley (GUN), Harrington barley (HAR), or 50% Gunhilde + 50% Harrington (MIX) as basal grains	29
3. In vivo digestion of finishing diets containing corn, Gunhilde barley (GUN), Harrington barley (HAR), or 50% Gunhilde + 50% Harrington (MIX) as basal grains.....	30
4. Carcass characteristics of steers fed finishing diets containing corn, Gunhilde barley (GUN), Harrington barley, or 50% Gunhilde + 50% Harrington (MIX) as basal grains.....	32
5. Characteristics of digestion in steers fed finishing diets of corn, Gunhilde barley (GUN), Harrington barley (HAR), or 50% Gunhilde + 50% Harrington (MIX) as basal grains.....	41
6. Ruminal volatile fatty acids of steers fed finishing diets of corn, Gunhilde barley (GUN), Harrington barley (HAR), or 50% Gunhilde + 50% Harrington (MIX) as basal grains.....	49
7. Analysis of variance for feedlot trial comparing finishing diets of corn, Gunhilde barley (GUN), Harrington barley (HAR), or 50% Gunhilde + 50% Harrington (MIX) as basal grains.....	63
8. Analysis of variance for metabolism trial comparing finishing diets of corn, Gunhilde barley (GUN), Harrington barley (HAR), or 50% Gunhilde + 50% Harrington (MIX) as basal grains.....	64

LIST OF FIGURES

Figure	Page
1. Ruminant fluid ammonia concentration of steers fed finishing diets of corn, Gunhilde barley (GUN), Harrington barley (HAR), or 50% Gunhilde + 50% Harrington (MIX) as basal grains.....	46
2. Ruminant fluid pH of steers fed finishing diets containing corn, Gunhilde barley (GUN), Harrington barley (HAR), or 50% Gunhilde + 50% Harrington (MIX) as basal grains	48
3. In situ dry matter disappearance of steers fed finishing diets containing corn, Gunhilde barley (GUN), Harrington barley (HAR), or 50% Gunhilde + 50% Harrington (MIX) as basal grains.....	50

ABSTRACT

Two trials were conducted to determine the effects of high concentrate diets of corn or barley. Diets were corn (control); Gunhilde barley (GUN); Harrington barley (HAR); and 50% Gunhilde + 50% Harrington (MIX). Trial one evaluated feedlot performance and carcass characteristics of beef steers fed corn or barley. Eighty crossbred steers were utilized in a randomized complete block design. Trial two examined ruminal digestion of steers fed high concentrate diets of corn or barley. Four ruminally and duodenally cannulated steers were used in a 4 X 4 Latin square designed metabolism trial. Corn-fed steers gained 7% faster ($P = .04$) than barley-fed steers. No other differences ($P > .10$) in animal performance were seen when barleys were compared. Dry matter intake for corn-fed steers was higher ($P = .0002$) yet feed efficiency was not different ($P > .05$) between diets. Harrington had greater ($P = .01$) total starch and digestible starch intake than GUN. Gunhilde had greater ($P = .01$) DMD than HAR-fed steers. Corn-fed steers had greater ($P < .10$) hot carcass and kidney/heart/pelvic fat% than barley-fed steers. Feed cost and cost of gain for barley rations was lower ($P = .002$) than corn rations. Starch flow to the duodenum was greater ($P = .004$) for corn-fed diets. Total tract starch digestion, along with DM and N, were greater ($P = .03$) for barley-fed steers. No associative effects ($P > .10$) were seen in nutrient flow to the duodenum or ruminal digestion (%) when MIX was compared to GUN/HAR. GUN had greater ($P = .003$) retention time and lower ($P = .007$) flow rate than HAR-fed steers. Corn-fed steers had greater ($P < .05$) animal performance when compared to steers fed barley. With feed efficiencies similar ($P > .05$), lower feed cost of barley based diets make them an attractive alternative to corn in the Northern Great Plains and Pacific Northwest region. We observed similar animal performance and metabolic traits of GUN and HAR in these trials. This trial reaffirms the need for research into environmental and growing location that affect feeding values of barley.

CHAPTER 1

INTRODUCTION

In 1999 1.25 million acres of Montana were planted in barley. This ranked second in the nation behind North Dakota which planted 1.42 million acres. The major varieties of barley planted in Montana were: Harrington (49.9%), Baronesse (7.6%), Busch 1202 (5.2%), and a number of other varieties at < 5.0% (Montana Agricultural Statistics Service, 1999). In the United States, barley is used mainly in brewing beer and as an energy supplying cereal grain in livestock feeds. Grown for many centuries, barley performs well in the arid, cold climate of the Northern Great Plains and Pacific Northwest region. Regional feedlot operators utilize barley as the principal energy source in many of their finishing feedlot rations. The national standard for the malting cultivars is the Morex variety. However, no current standard exists for the feeding grades. Classification of these cultivars, whether of a feeding or malting type, is typically based on malting characteristics rather than actual feeding value (Gibson et al., 1994; Molina-Cano et al., 1997).

Commonly viewed as the 'second sister' to corn as a livestock feed, the importance of barley has not been over looked by the scientific community. Barley varieties have demonstrated differences in test weight, chemical composition, nutritive values, and yield potentials (Kemalyan et al., 1989), as well as differences in animal performance and carcass characteristics (Milner et al.,

1995). Variability in cultivars has been attributed to geographical location, growing conditions, year (Kemalyan et al., 1989), and head morphology (Bowman et al., unpublished).

These variations in barley cultivars have caused differing results in feed trials. Boss and Bowman (1996a) reported corn-fed steers had greater ADG and DMI than did those steers fed barley. Conversely, Milner et al. (1995) found no differences in animal performance with high concentrate diets of either corn or barley as the basal grain. A major advantage of feeding corn over barley is its consistent performance. Differences in corn varieties do not seem as pronounced as those differences observed with barley cultivars. It is generally accepted that this is due to a greater amount of corn starch escaping ruminal fermentation and being presented to the small intestine for digestion (Ørskov, 1986).

Metabolically, the main focus of barley research has fallen on site and rate of starch digestion by the ruminant animal. Factors affecting barley starch digestion include cultivar type, bulk density, grain processing techniques, and flow rate and retention time both ruminal and post-ruminal. Few trials have been published that compare different barley varieties and their effect on animal performance. Fewer still have compared metabolic factors that may be affecting these differences between barley varieties. Boss and Bowman (1996b) found no differences in extent of starch digestion among three barley cultivars. The authors did report that Gunhilde (a feed grade barley) had a 30% slower rate of ruminal starch digestion than did Harrington (a malting variety).

Based on the Boss and Bowman (1996a; 1996b) trials, the objectives of this study were to:

1. Evaluate feedlot performance of beef cattle consuming high grain diets differing in rate of starch digestion.
2. Determine if an associative effect would result from feeding a malting variety barley with a fast rate of ruminal starch digestion in combination with a feed barley with a slow rate of ruminal starch digestion.
3. Evaluate site and efficiency of starch digestion in beef calves consuming high grain diets differing in rate of starch digestion.

CHAPTER 2

LITERATURE REVIEW

Grain Processing

The goal of all grain processing techniques is to damage the pericarp making starch granules contained within the endosperm more readily digestible and fermentable. Processing has been shown to be one of the simplest ways to manipulate nutritive values of cereal grains. Fibrolytic, proteolytic and amylolytic enzyme activity is improved by processing, increasing ruminal efficiency (McAllister et al., 1993a). When whole barley was compared to dry-rolled or steam-rolled barley, improved utilization and digestibility was observed by processing (NRC, 1996). Processing of cereal grains as described by Church (1986) can be classified as either dry processing or wet processing. Dry processing includes whole grain, grinding, dry rolling or cracking, popping, extruding, micronizing, roasting and pelleting. Wet processing includes soaking, steam rolling, steam processing and flaking, exploding, pressure cooking and high-moisture fermentation of early harvested and reconstituted grains.

Zinn (1993b) found that steam-rolling oats increased energy values 7.6% over dry-rolling oats. In a review paper, Owens et al. (1997) reported no differences ($P > .05$) in ADG or DMI when steam-flaked barley or milo were compared to dry-rolled. Average daily gain for corn was not different in the same

comparison, however DMI and feed:gain were greater ($P < .05$) for dry-rolled corn (9.45 kg/d and 6.57) when compared to steam-rolled corn (8.35 kg/d and 5.87).

In addition to steam-rolling, Zinn (1993b) also examined flake size. Results showed that steers fed steam-rolled thin flaked oats had 13.2% lower ($P < .01$) ADG and 11.1% higher ($P < .05$) feed:gain than those steers fed steam-rolled coarse flaked oats. He also observed greater ($P < .01$) hot carcass weights (310.1 vs 295.0 kg) and % KPH (2.26 vs 1.95, $P < .05$) for coarse flakes when compared to thin flakes. Net energy values were negatively affected in the trial by thin flaking. This is in agreement with other reports that over-processing may be detrimental to animal performance.

Owens et al. (1997) stated that in general, ADG was reduced the more grain was processed. This may be attributed to a decrease in DMI brought about by an increase in acid production within the rumen as fermentation rate increases. The more a grain is processed, the faster the rate of fermentation and passage, causing an increase in the production of acids within the ruminant environment. This can lead to sub-clinical acidosis and a day-to-day change in DMI.

Bradshaw et al. (1992) compared two barley varieties (Steptoe and Klages) and found that processing method affected ($P < .05$) DMD, DE, and gross energy digestibility while having no influence ($P > .05$) on ADF, NDF, and CP digestibility. They tested dry-rolling, tempering and rolling, tempering plus ammoniating and rolling, and tempering plus ammoniating and whole. Steers fed

dry-rolled grain had higher ADG for the growing phase as well as 15% better ($P < .05$) total trial feed efficiency than those steers fed whole barley.

Pritchard and Stateler (1997) studied diet-mixing characteristics of processed grains. They determined that processing could have a positive or negative effect depending upon mixing conditions and other dietary ingredients. They also addressed the possibility of associative effects when combining differing grains, suggesting that positive performance results may be attributed to the integrity of diet mixing.

Processing may alter how a diet is consumed, which may in turn effect animal nutritional status and performance. Digestible energy and ME values of the Pritchard and Stateler (1997) trial closely compared to NRC (1996) values (3.58 and 2.91 Mcal/kg compared to 3.44 and 2.82 Mcal/kg, respectively). Though there appears to be minimal benefits to processing oats (NRC, 1996 and Zinn, 1993b), differences in animal performance have been observed with processing of other cereal grains. Bradshaw et al. (1996) reported improvements in animal performance when fed processed as compared to whole grain barley. Average daily gain for steers fed processed grains were greater ($P < .05$) than those fed whole grains, prompting the authors to suggest that processing is a must for optimal performance. Combs and Hinman (1989) and Zinn (1993a) also observed improvements in animal growth performance with various types of barley processing. While examining corn hybrids, Ladely et al. (1995) found that method of grain processing had a greater affect on animal performance than did hybrid. Their report showed that processing method could influence animal gain

and feed efficiency. High-moisture grain-fed animals gained faster on less feed than those animals fed dry-rolled grains.

Anderson and Boyles (1989) suggested that there was an advantage to feeding grain combinations as opposed to feeding one particular grain. They fed three diets of corn and barley reporting that the diet containing 60% barley/24% corn had slower daily gains (1.17 kg/d) than those diets containing 35% barley/47% corn (1.29 kg/d) or 10% barley/70% corn (1.30 kg/d). However they did not compare any of the diets to a single grain source.

Digestive Disorders

Ruminant animals evolved consuming predominantly roughage-based diets. The addition of processed grains as a primary food source to these animals is a man-made decision. Conversion of a forage diet to a cereal grain, changes microbial fermentation from plant cell walls to cereal grain starch (McAllister and Cheng, 1996). Feeding high concentrate diets creates the possibility of certain health disorders developing due to the rapid fermentation of these high grain diets. With this increased digestibility and rate of passage, incidences of acidosis and bloat also increase in feedlot animals. To properly diagnose fatal digestive disorders, a complete necropsy is necessary including checking ruminal pH. Miles et al. (1998) suggested that many cases should be diagnosed as "unknown" or "undetermined".

Acidosis is defined as a decrease in the alkali (base excess) in body fluids relative to the acid (hydrogen ion) content (Owens et al, 1998). It is important to note that there is no clear description of an acidotic animal but rather degrees to which an animal is acidotic. These degrees range from reducing the animals daily feed intake to death (Stock and Britton, 1992). Diseases related to acidosis include: sudden death syndrome, polioencephalomalacia, founder, rumenitis, liver abscesses, malabsorption, clostridial infestations, and reduced feed intake.

The most common occurrences of acidosis occur in the initial warm-up stages of high-concentrate diets. At this time the animal consumes a large quantity of readily fermentable starches and other carbohydrates. These starches are rapidly hydrolyzed to glucose creating a large presence of free glucose in the rumen. Owens et al. (1998) suggested that this could have three adverse effects. In a free glucose environment, *Streptococcus bovis*, a normally non-competitive bacterium, may thrive producing lactic acidosis. Second, microbes such as coliforms and amino acid decarboxylating microbes produce or release endotoxins or amides. Finally, there is an increase in osmolality that intensifies the accumulation of acid within the rumen by inhibiting VFA absorption.

Actual identification of acidosis depends on a clinical measurement of blood and ruminal pH, with chronic and acute acidosis ruminal pH values of 5.6 and 5.2 being used as marks (Owens et al., 1998). Acidosis may be broken into acute and subacute. Included in acute acidosis is polioencephalomalacia (PEM). Since this disease affects the brain, diagnosis is marked by blindness,

incoordination, and seizures (Gould, 1998). Feedlot causes of this disease may be associated with, but not confined to, diets high in sulfates such as those containing molasses. Animals afflicted with this disease often respond to injections of thiamin though there may or may not be any metabolic alterations in thiamin status (Gould, 1998). Prevention of acidosis may decrease the occurrence of this disease (Galyean and Eng, 1998).

Many cases of acute acidosis go undetected. However due to a decrease in ruminal pH, damage to the lining of the ruminal wall, abomasal and intestinal linings reduces the absorption of nutrients creating what are known in the industry as "poor doers". These are animals that have low average daily gains and poor feed to gain ratios (Stock and Britton, 1992). Common conditions such as founder, which may show up well into the feeding period or sudden death, are often closely associated with bloat.

In a feedlot situation virtually every animal will experience some form of subacute acidosis. A very difficult condition to detect, some signs such as panting, excessive salivation, kicking the belly, and eating dirt may be observed (Stock and Britton, 1992). These cases are often followed by decreases in feed intake. Besides management techniques, another factor that may create subacute acidosis is a change in the animals' environmental conditions. Extremes in temperatures, storms, or mud may all cause the animals to change their level of feed intake.

As common as, and often associated with, acidosis in feedlot animals is bloat. Bloat is a ruminal dysfunction that results from the accumulation of

excessive gas within the rumen (Cheng et al., 1998). Under normal conditions, gases produced by fermentation are eliminated by eructation (Duren and Miller, 1992). Causes of bloat are feeding management, individual animal physiology, diet, and microbial factors. Bloat may be classified as either free-gas bloat or frothy bloat. Frothy bloat accounts for 90% of all feedlot bloat cases though free-gas bloat has the higher mortality rate (Cheng et al., 1998).

Free-gas bloat can occur when gases are prevented from escaping the rumen by a blockage of the esophagus. Impaired rumen motility, as caused by acidosis, may also result in this form of bloat (Cheng et al., 1998). Much like acidosis, feedlot bloat occurs most commonly as animals are being adapted to high-concentrate diets. Similar to acidosis, the bacteria *Streptococcus bovis* is commonly associated with bloat. With high availability of glucose (high energy) in the rumen, these bacteria can produce an increased rate of rumen fluid viscosity (slime). This high viscosity is associated with frothy bloat (Cheng et al., 1998; Russell, 1998).

Sudden death in feedlot cattle is a loosely used term. Often this term is used to cover a number of undiscovered factors that attributed to the death of an animal. Most often the term is used in cases where an animal, usually near market weight, dies unexpectedly and usually at night (Glock and DeGroot, 1998). These animals rarely exhibit any form of illness or discomfort and lack a clear cause of death. In a review on the subject, Glock and DeGroot (1998) reported that the most common causes of sudden death were acidosis and bloat.

Nagaraja and Chengappa (1998) found that liver abscesses, commonly occurred in animals on an aggressive high-concentrate feeding program. They reported finding that most feedlots had from 12 to 32% of their animals affected by liver abscesses. Incidences and severity was attributed to amount of roughage in the diet. The less roughage in the diet the greater the level of abscesses. Addition of tylosin (fed at a rate of $90 \text{ mg} \cdot \text{animal}^{-1} \cdot \text{d}^{-1}$) to the ration can reduce the incidence of liver abscesses from 40 to 70%. The addition of tylosin was also reported to increase average daily gains 2.1% and feed to gain ratios by 2.6%.

More important for the producer is the economic impact that these disorders have on production. The focus then becomes prevention. As discussed earlier, cereal grains differ in their rates of digestion. A list of grains from rapid to slower rates of fermentation are wheat, barley, sorghum, and corn. Differences in ruminal digestion of starch may be attributed to the protein matrix surrounding it within the endosperm of the various grains (McAllister et al., 1993a). An increased rate of fermentation also results from grain processing. Understanding the causative factors will help reduce the occurrence of many of these feeding disorders. Control of these disorders starts with proper bunk management. Proper formulation of rations, thorough ration mixing, and consistent feeding time all will help in reducing these diseases. It is accepted that increasing the amount of roughage within the diet will reduce incidences of both acidosis and bloat. In addition to increasing roughage amounts, including bicarbonate buffers and ionophores to high-concentrate diets has been shown to

reduce acidosis and bloat. Monensin was reported by Owens et al. (1998) to reduce variations in daily feed intakes by controlling certain lactate-producing bacteria. Both these factors would positively influence these digestive disorders.

Starch Structure and Function

Starch is the storage form of polysaccharides in plant cells (Lehninger et al., 1993) and the major component of non-structural carbohydrates in ruminant diets. Polysaccharides, or glycans, are carbohydrates that upon oxidation provide the central-energy-yielding pathway in most non-photosynthetic cells. Volatile fatty acids are the product of fermentation of non-structural carbohydrates within the rumen or large intestine. Starches may also be digested and absorbed as glucose in the small intestine (Allen and Knowlton, 1995). There are two types of glucose polymers (semi-crystalline structures) within starch. Amylose, which is unbranched, and amylopectin, which is highly branched. These polymers are primarily connected by α 1- 4 linkages. At the branch points are α 1- 6 linkages. In animal cells the storage form of polysaccharides is glycogen which contains both forms of linkages (Kotarski et al, 1992). Research has focused on energy content and availability within cereal grains and how to maximize its utilization.

Protected by the pericarp of the cereal grain is the starch-containing endosperm. Within this endosperm is a protein matrix that may determine ruminal bacterial access to starch granules (McAllister et al., 1993a). McAllister et al., (1993a) examined the protein matrix of corn and barley starch and found

that, when isolated, these starches were digested equally in the rumen. They concluded that starch granule structure was not the cause of differences in ruminal digestion between the two grains. They identified structural components of the endosperm's protein matrix in corn and structural carbohydrates in barley as the limiting factors. Their result demonstrated that barley protein matrix is more readily digested by ruminal microbes than its corn counterpart. This does not mean that the protein matrix of barley is readily digestible. Allen and Knowlton (1995) reported that disrupting the matrix allows increased access to starch granules by microbial enzymes, and may be the major factor affecting ruminal starch digestion. Bowman et al. (1996) suggested that specific proteins within the barley endosperm may control the ability of ruminal microorganisms to digest this cereal grain. McAllister et al. (1993b) presented data that rumen fungi are proteolytic and effective in breaking down the protein matrix of wheat and barley.

Studying endosperm structure and starch in waxy, normal and high amylose barleys, Oscarsson et al. (1997) reported that different types of starch granules could be found in different parts of the endosperm. They reported that in Glacier barley (a high amylose variety) starch granules were more even in size and tightly packed in the subaleurone layer. Starch granules were larger in size in Golf barley (a normal variety) which demonstrated bimodal distribution. Wester et al. (1992) stated that most starch is not as susceptible to enzymatic degradation as the primary component of waxy starches, amylopectin. Within the floury endosperm, located beneath the protective protein matrix layers, are

starch granules that are most susceptible to digestion or grain processing (Huntington, 1997; McAllister and Cheng, 1996). Lorenz (1995) suggested that amylose reinforced starch granule structure became more resistant to enzymatic activity. With barley varieties being reported as having differences in chemical composition and nutritive values (Kemalyan et al., 1989), it is interesting to note that Oscarsson et al. (1997) found no differences in cell-wall thickness, cell size, or starch granule characteristics between the different barleys studied due to growing location.

Brown (1996) proposed three categories of cereal grain starch digestion; 1) Rapidly digested starch, such as in those cases where the grain has been processed in some way; 2) Slowly digested starch, from unprocessed grain sources; 3) Starches that are resistant to digestion. Resistant starch granules are present in processed and unprocessed grains and are trapped within the protein matrix of the grain. When the hydrogen bonds that make up the matrix are broken, such as occurs with gelatinization, the starch then becomes available for fermentation. It has been shown that with extensive processing techniques gelatinization of starches does occur (Theurer, 1986). In order for the animal to better utilize grain starch, the endosperm needs to be damaged in some way. Increasing the surface area of a grain by processing increases both the rate of fermentation and ruminal digestion of starch. With increased digestion rates, rate of passage also increases. Theurer (1986) showed that steam-flaked sorghum had approximately a three fold greater rate of ruminal starch digestion than ground sorghum.

Leloup et al. (1992) reported that both granular disorganization and increased porosity of the grain, once gelatinized, greatly increased digestibility. They reported that amylose and amylopectin react differently due to porosity, chain length, chain orientation, accessibility of chain extremities, and temperature. They concluded that physico-chemical properties of starch control the rate and extent of enzymatic hydrolysis and its digestibility.

In an effort to understand feed quality characteristics of differing barley varieties, research has focused on the genetic factors that influence cereal grains. Bowman et al. (1996), in cooperation with the North American Barley Genome Mapping Project, reported substantial differences among barley genotypes for starch, crude protein, digestibility and particle size. They found that chromosome 4 contained the primary region (quantitative trait loci) that was responsible for digestibility of ground barley. Also found in this region of chromosome 4 were quantitative trait loci for ADF content and crude protein. There was a correlation between grain characteristics that are located in the same loci and endosperm degradation during germination and within the rumen.

Ruminant Starch Utilization

Cereal grains have differing amounts of starch content. Barley and oats are lowest at 58% starch, followed by sorghum and corn (72%), and finally wheat at 77% on a DM basis (Huntington, 1997). In addition, ruminant utilization of starch from these grain sources also differs.

Ruminal digestion of starch can be extensive and varies depending upon the grain and processing technique used. Huntington (1997) found that steam processing increased starch digestibility of sorghum by 26%, corn by 10%, and 6% or less for other grains, over dry-rolling. In a review, Allen and Knowlton (1995) reported that steam-flaking sorghum, corn or barley consistently increased ruminal starch digestion when compared to dry-rolling of these respective grains. Theurer et al. (1999) examined the effect of grain processing method and degree of processing on site and extent of DM, starch, and N digestion. Comparing steam-flaking and dry-rolling sorghum, they found that starch flow to the duodenum was greater for dry-rolled sorghum (1322 vs 665 g/d). Ruminal and total tract digestibility, as a percent of intake, were both lower ($P = .01$) for steers fed dry-rolled as compared to steam-flaked sorghum. This resulted in lower small ($P = .01$) and large ($P = .05$) intestine starch digestibility for dry-rolling compared to steam-flaking. These results reaffirm the findings on lower tract starch digestibility reported by Theurer (1986). Reduction of flake density in the trial increased ($P = .01$) overall percentage of starch digested by the steers. Owens et al. (1986) reported that large granule starch reaching the duodenum is poorly digested by both the small and large intestine.

Up to 90% of oat, barley or wheat starch can be fermented within the rumen (Ørskov, 1986). With corn, as much as 40% of the starch can escape ruminal fermentation and be presented to the small intestine for further digestion. This slow rate of ruminal starch digestion can be attributed to the protein matrix resistance to invasion. This is not the case with barley or wheat grain, where the

protein matrix is readily attacked by proteolytic bacteria (McAllister and Cheng, 1996). Spicer et al. (1982) suggested that total tract starch digestibility was related to the amount of starch fermented in the rumen. However, increased rate of ruminal starch digestion does not always positively relate to improved animal performance (Wester et al., 1992)

Within the rumen is a biomass containing bacteria, protozoa, fungi and various enzymes. This microflora competes for colonialization of the substrates presented to the rumen. High concentrate diets increase rate of fermentation and subsequently effect ruminal pH and the microbial population. Levels of these microbes vary depending on rumen environmental conditions.

Accounting for up to 8% of the total ruminal biomass, fungi are adapted to breaking down structural carbohydrates (McAllister and Cheng, 1996). While studying three fungi strains (*Orpinomyces joyonii*, *Neocallimastix patriciarum*, and *Piromyces communis*), McAllister et al. (1993a) noted that all strains were proteolytic. This allows the fungi the ability to breakdown the protein matrix and digest starch granules. Due to slow growth, they are limited in their ability to compete with ruminal bacteria for starch. Ruminal fungi have been reported to exist in equal numbers whether the diet is high in forage or concentrate (McAllister and Cheng, 1996). They have also been reported by the authors to be the only microorganisms capable of breaking down the protein matrix of corn. The damage fungi cause to cereal grains may allow bacterial attachment (McAllister et al., 1994).

Protozoa are estimated to make up 20 to 45% of the amylolytic activity in the rumen (McAllister and Cheng, 1996), with a starch ingestion rate inversely correlated with starch granule size. The rumen environment also controls populations of protozoa. Numbers will increase as concentrates are added, but decrease when the diet is 80% concentrate or greater. Lowered ruminal pH is thought to hinder protozoan populations (Kotarski et al., 1992). One of the benefits of protozoa is their ability to reduce starch degradation rate and to moderate ruminal pH after feeding by predation of amylolytic bacteria. Protozoa are capable of storing large amounts of starch and metabolizing it at a slow rate. This limits lactic acid production and the resulting lower pH level due to rapid starch fermentation (Kotarski et al., 1992; Nozière and Michalet-Doreau, 1997). Protozoa, however, are not essential to starch digestion.

Streptococcus bovis and *Ruminobacter amylophilus* are the primary amylolytic bacterial species within the rumen (Nozière and Michalet-Doreau, 1997). A number of other amylolytic species have also been identified including: *Bacteroides* sp., *Bifidobacterium pseudolongum*, *thermophilum* and *adolescentis*, *Borrelia* sp., *Butyrivibrio* sp., *Eubacterium ruminantium*, *Ruminobacter amylophilus*, *Ruminococcus bromii*, *Succinimonas amylolytica* and *Lactobacillus* sp.. These bacteria secrete amylase or produce surface-associated amylases in order to hydrolyze starch. They are not capable of ingesting the granules like protozoa (Kotarski et al., 1992), but are responsible for the majority of ruminal starch fermentation (Huntington, 1997). Ruminal carbohydrate-fermenting bacteria produce volatile fatty acids (VFA's), mainly acetate and propionate.

When a grain, whole or processed, becomes part of the rumen substrate, it is colonized by site-specific bacteria (McAllister et al., 1990; Kotarski et al., 1992). As digestion continues, these bacterial colonies work together to become larger. Many different bacteria may colonize starch of cereal grains other than corn. However, for corn coccoid bacteria are the predominant colonizers.

Research has shown that amylase activity increases after feeding cereal grains such as barley (Nozière and Michalet-Doreau, 1997). Activity levels for barley were reported to be higher than that of corn. The authors also showed that maximum amylase production from amylolytic bacteria was dependent upon amount of starch available. This was digestible starch available and not total starch. When an excess of carbohydrates are available, as occurs from feeding high concentrate diets, the glucose is converted to lactate (Russell, 1998). Fifteen to twenty percent of glucose production by the liver is from lactate (Nocek, 1990).

Ørskov (1986) and Theurer (1986) suggested that increased ruminal starch digestion would improve efficiency of gain. Owens et al. (1986) and Nocek (1990), conversely, stated that starch digested in the small intestine of growing ruminants increased energetic efficiency. This is due to ruminal losses in heat and methane production during fermentation (Ørskov, 1986). Owens et al. (1986) also reported that ruminally digested starch of corn and sorghum grain was utilized 42% more efficiently in the small intestine than if digested in the rumen. This is to say that energy absorption by the small intestine is more efficient than fermentation in the rumen. Of total starch intake, 5 to 20% is

digested postruminally, most in the small intestine (Huntington, 1997). In the Allen and Knowlton (1995) review, it was reported that with processed grains, starch digestion in the small intestine was from 47 to 88% and in the large intestine 33 to 66% of total starch presented to these respective organs. Grain processing not only increases ruminal starch digestion, but also lower tract and therefore total tract starch digestion. Owens et al (1986) concluded that intestinal starch digestion is limited only by the amount of starch escaping ruminal fermentation. The efficiency of starch digestion, however, decreases as more starch enters the lower tract.

CHAPTER 3

FEEDLOT PERFORMANCE AND CARCASS CHARACTERISTICS OF BEEF
STEERS FED CORN OR BARLEYIntroduction

Barley has long been the grain of choice for finishing rations in the Northern Great Plains and Pacific Northwest region, since it is well adapted to the growing conditions of the region. Area farmers currently grow many different barley varieties of both malting and feed grades. Recent research has demonstrated that animal performance varies depending on variety of barley fed (Milner et al., 1995; Boss and Bowman, 1996a; Ovenell-Roy et al., 1998a). Variations in carcass characteristics have also been observed when different barley varieties were fed (Boss and Bowman, 1996a; Ovenell-Roy et al., 1998a).

Boss and Bowman (1996a) reported steers fed Gunhilde barley had lower ADG and DM intake compared with steers fed Harrington barley. In addition, Gunhilde had 30% slower ruminal starch digestion rate than Harrington (Boss and Bowman, 1996b). Tyrrell and Moe (1974) reported slow ruminal starch digestion to be desirable in a feed grain. Their study was designed to determine the effects of barley variety and corn on animal performance, and to determine if associative effects resulted from feeding a malting barley variety in combination with a feed grade barley.

Materials and Methods

Eighty crossbred Hereford/Angus steers (average wt 420 kg) were used to evaluate animal performance and carcass characteristics when fed high concentrate diets of barley or corn. Steers were contemporaries selected from three Montana Agricultural Experiment Station beef herds. These stations were: Red Bluff Research Station (Norris, MT) supplying 34 steers; Livestock Teaching and Research Center (Bozeman, MT) 30 steers; and Bandy Research Ranch (Ovando, MT) with 16 steers.

Calves from Red Bluff Station and Livestock Center were vaccinated August 31, 1994 with a clostridial 8-way and Triangle 4+ *Haemaphysus somnus*. Calves were then weaned October 19. All calves (steers and heifers) were penned together at the Livestock Teaching and Research Center. Calves were group fed grass hay on October 20. October 21 they were given 2.3 kg/h barley, 3.7 kg/h on October 22, and 4.5 kg/h on October 23. This final ration was fed up to November 1. Corn (of an unknown variety) for the finishing trial was received on October 28 with a bushel weight of 55 lbs/bu. On November 1, all calves were placed on a ration of 50% chopped hay and 50% barley. Heifer and steer calves were separated on November 19. Steers from Bandy Research Ranch arrived at the Livestock Center November 2, 1994. These animals were kept separate from the main group of calves until November 19 when they mixed with the other steers.

Steer calves were implanted with Synovex S, wormed with Ivomectin and fed a starter ration (40/60 barley to chopped grass hay) as a group beginning January 10, 1995. This ration was stepped up 10% every six days to a final ration not exceeding 80% barley in the total diet. The 80% barley ration was fed up to the beginning of the finishing trial on April 6. Intakes on an as-fed basis on February 7 were 7.7 kg/h/d. On February 21 the intakes were 8.3 kg/h/d. Steers were weighed February 24, at which time steers for the Gibson/Bowman calan gate trial were selected and removed from the main group of steers. Steers to be cannulated were also removed from the group at this time. Three steers from Red Bluff and one steer from Livestock Center (no implants) were used in the corresponding 4 X 4 trials.

Steers were assigned by weight to one of 16 pens in a randomized complete block design, with 4 pens per treatment. The four treatments were 1) corn; 2) Gunhilde, a six-row European feed grade barley (GUN); 3) Harrington, a two-row malting barley (HAR); and 4) 50% Gunhilde/50% Harrington (MIX). Gunhilde represented a slow rate of ruminal starch digestion, with Harrington having a fast rate of ruminal starch digestion (Boss and Bowman, 1996b). Diets were balanced to be isonitrogenous (13.5% CP), isocaloric (1.93 Mcal/kg NE_m , 1.28 Mcal/kg NE_g), and to contain 83% grain on a dry matter basis.

Table 1. Composition (%DM basis) of finishing diets containing corn, Gunhilde barley (GUN), Harrington barley (HAR), and 50% Gunhilde + 50% Harrington (MIX) as basal grains.

Item	Corn	GUN	HAR	MIX
Ingredients, % of DM				
Corn	82.00	-----	-----	-----
Gunhilde barley	-----	83.00	-----	41.50
Harrington barley	-----	-----	83.00	41.50
Oatlage	6.00	6.00	6.00	6.00
Molasses	4.00	5.00	5.00	5.00
Soybean Meal	3.54	1.69	1.31	2.24
Urea	1.25	.30	.83	.42
Sodium bicarbonate	1.30	1.30	1.30	1.30
Calcium bicarbonate	.57	1.38	1.25	.72
Sodium chloride	.50	.50	.50	.50
Potassium chloride	.50	.50	.50	.50
TM premix ^a	.25	.25	.25	.25
Vit. A, D, E premix ^b	.05	.05	.05	.05
Rumensin 80 ^c	.024	.024	.024	.024
Tylan 40 ^c	.013	.013	.013	.013
Chemical composition				
DM %	87.64	91.02	91.24	90.95
OM, % of DM	94.17	92.53	93.99	92.83
CP, % of DM	13.46	14.36	15.07	14.36
Starch, % of DM	48.47	37.00	41.85	40.43
ADF, % of DM	6.38	8.80	8.03	8.94
AIA, % of DM	.4914	.6980	.8178	1.0435

^aContains 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.

^bContains 30,000 IU/g vitamin A, 6,000 IU/g vitamin D, and 7.5 IU/g vitamin E.

^cRumensin 80 contained 132 g/kg of monensin. Tylan 40 contained 88 g/kg tylosin

Barley with similar bushel weights were used (average .62 kg/L or 49.5 lbs/bu) to remove any differences in performance that might be attributed to bushel weight. All grains were coarsely cracked through a Denver, Inc. hammer mill prior to mixing. Molasses and oatlage were added to each respective ration to reduce dust and attempt to equalize palatability of the four diets. Steers were fed once daily between 0730 and 0900. Each diet supplied 360 mg monensin and 90 mg tylosin per d. Diet composition is presented in Table 1.

An adaptation period of 28 d was used to adjust steers to their respective high concentrate diets. Initial (April 4 & 5, 1995) and final (July 9 & 10, 1995) weights were obtained on consecutive days and averaged, with steers weighed before feeding to remove differences that might occur due to individual fill. These average weights represented on and off trial weights for steers. Over the 96 d trial animals were weighed every 28 d. Weigh days were May 3, and 31, and June 28, 1995.

Feed grab samples were collected throughout the trial, composited by diet and analyzed for DM, OM, CP, (AOAC, 1997), AIA (Van Keulen and Young, 1977), ADF (Van Soest et al., 1991), and starch (Megazyme, Sidney, Australia). Feed samples were collected on April 17 and 25, May 9 and 23, and June 2, 13, and 20. Grab samples of the supplement were taken May 2, June 2, and June 20. Acid insoluble ash was used as an internal marker to estimate fecal output. Fecal grab samples were taken from each steer during the 56 d weighing and composited by pen. Analysis for DM, OM, CP, AIA, ADF, and starch were performed. Fecal samples were taken on the last days of the trial, July 9 and 10 and composited by pen. Analysis of samples was performed to determine in vivo nutrient digestibilities.

Steers were slaughtered (E. A. Miller, Hyrum, Utah) when it was visually estimated that 80% would grade Choice. Steers were shipped from the Livestock Center on two consecutive days. Forty head were shipped July 11 and slaughtered July 12, with carcass data collected July 13. The second shipment of 40 head left July 12, was slaughtered July 13, with carcass data collected July

14. After a 24 h chill, backfat thickness, and ribeye area were measured. Percentage kidney, heart, and pelvic fat, marbling score, and yield and quality grades were assigned by a USDA grader.

Data were analyzed using the GLM procedure of SAS (1993) with pen as the experimental unit. Performance and carcass data were analyzed in a randomized complete block design. The blocks were the north and south sides of the feedlot. Hot carcass weight was used as a covariate for carcass characteristics. Planned comparisons were made for: corn vs barley, GUN vs HAR, and MIX vs GUN and HAR. Treatment least square means were separated by the LSD method of SAS (1993) if treatment F-test was significant ($P < .10$). Least square means and associated standard errors are reported.

Results and Discussion

Corn-fed steers gained 7% faster ($P = .06$) than barley-fed steers (1.63 vs 1.52 kg/d; Table 2). These results agree with Boss and Bowman (1996a) who reported corn-fed steers gained 10% faster ($P < .01$) than steers fed HAR (1.43 vs 1.30 kg/d). They also reported that HAR fed steers gained 8% faster ($P = .002$) and were 22 kg heavier than those steers fed GUN or MED at the conclusion of the study. Milner et al. (1995) reported no differences ($P > .10$) in ADG between steers fed finishing diets of corn or barley. This trial observed corn-fed steers having a 12% greater DM intake than the barley varieties examined. No differences between diets ($P > .10$) in feed:gain occurred.

Boss and Bowman (1996a) found steers fed corn were 23 kg heavier ($P = .001$) than steers fed barley. In this trial, corn fed steers weighed 10.6 kg more than barley fed steers ($P = .06$) in final weights. Ovenell-Roy et al. (1998a and 1998b), in similar feed trials comparing six barley varieties, found few differences in ADG between varieties. Average daily gain over the length of their trial was improved in the second year, with feed:gain remaining about the same (6.6 and 6.4 respectively). Boss and Bowman (1996a) also reported no difference ($P > .10$) between GUN and HAR in feed:gain. In our trial we found no differences ($P > .10$) in ADG or feed:gain when comparing GUN- and HAR-fed steers. Looking at the Boss and Bowman (1996a) results, our steers consuming HAR and GUN gained .22 and .30 kg/d more and had better feed:gain (15.8 vs 14.01 and 15.4 vs 13.70) when comparing the two trials.

Bradshaw et al. (1996) found that animal performance of steers fed a malting and a feed grade barley resulted in no differences in ADG until they altered processing technique. By feeding barley cultivars with similar bushel weights and processing the grains in the same manner, possible variations in animal performance brought about by these factors appear to have been controlled on our trial. Unlike Ovenell-Roy et al. (1998a), Boss and Bowman (1996a), and Milner et al. (1995), who reported differences in feedlot performance between animals fed diets based on different barley cultivars, our trial found no differences ($P > .10$).

Intake of DM and starch was greater ($P = .0002$) by corn-fed than by barley-fed steers. Starch intake by HAR-fed steers was also greater ($P = .0006$)

than that of GUN-fed steers. Feed conversions (feed:gain) was not different ($P > .05$) for barley compared to corn. This does not agree with the Boss and Bowman (1996a) study where barley-fed steers had more desirable ($P = .03$) gain:feed than corn fed steers (average 16.0 vs 14.3). No other differences ($P > .10$) in animal performance were observed between GUN vs HAR or MIX vs GUN and HAR. Feed cost for corn (\$.14/kg) and barley (\$.13/kg) were up \$.02 to \$.03/kg compared to the Boss and Bowman (1996a) trial. Feed cost per day ($P = .001$) and gain cost ($P = .002$) for barley-fed steers were lower (average \$1.47/d and \$.97/kg, respectively) than for corn-fed steers (\$1.82/d and \$1.12/kg). There were no differences ($P > .10$) observed in feed cost or gain cost between GUN vs HAR or MIX vs GUN/HAR. The lower cost of the barley diets and high availability in the Pacific Northwest makes them an attractive basal grain compared to corn.

Table 2. Performance by steers consuming finishing diets containing corn, Gunhilde barley (GUN), Harrington barley (HAR), or 50% Gunhilde + 50% Harrington barley (MIX) as basal grains.

Item	Corn	GUN	HAR	MIX	SE	<i>P</i>		
						corn vs barley ^a	GUN vs HAR ^b	GUN/HAR vs MIX ^c
No. of steers	20	20	20	20				
Initial wt, kg	419.0	419.2	418.7	419.5	1.77	.96	.82	.80
Final wt, kg	575.1	561.1	564.6	567.8	8.77	.06	.59	.36
ADG, kg	1.63	1.48	1.52	1.55	.041	.06	.49	.35
Nutrient intake, kg/d								
DM	13.01	11.12	11.32	11.65	.208	.0002	.48	.14
Starch	6.31	4.12	4.74	4.71	.086	.0001	.0006	.03
FE, gain/100 kg fed	12.52	13.30	13.41	13.32	.335	.07	.93	.81
Diet, Mcal/kg								
NE _m	1.90	1.98	2.00	1.98	.039	.09	.59	.76
NE _g	1.25	1.32	1.35	1.32	.035	.09	.59	.76
Feed cost, \$/kg	.14	.13	.13	.13	----	----	----	----
Feed cost, \$/d	1.82	1.44	1.47	1.50	.027	.0001	.56	.25
Gain cost, \$/kg	1.12	.98	.97	.97	.027	.002	.80	.83

^aComparison of corn vs barley.

^bComparison of Gunhilde and Harrington barley.

^cComparison of Gunhilde and Harrington barley vs MIX.

Dry matter and starch digestibility, and digestible DM intake were greater ($P = .001$) for steers fed barley diets than for steers fed corn (Table 3). No differences ($P > .10$) in digestible starch intake were seen due to diet. Boss and Bowman (1996a) and Milner et al. (1995) reported that corn-fed steers had greater ($P > .01$) digestible DM intakes than did those steers fed barley. Boss and Bowman (1996a) also found corn-fed steers had greater ($P = .001$) digestible starch intake than HAR fed steers. We observed similar results as reported earlier. We also found digestible starch intake was greater ($P = .01$) for HAR when compared to GUN. This is in agreement with Boss and Bowman (1996a) who also reported HAR with greater ($P < .10$) digestible starch intake than GUN. Harrington had lower ($P = .01$) DMD than GUN on our trial.

Zinn (1993a and 1993b) showed that steam processing of grains maintained a more stable ruminal pH than more destructive processing techniques. Ovenell-Roy et al. (1998a and 1998b) used steam processing on their respective trials and reported ADG, intakes, and ruminal pH values similar to those seen on this trial. Grains on this trial were dry rolled prior to feeding, one of the more destructive of the processing techniques.

Estimated grain NE_m and NE_g were higher ($P < .01$) for barley than for corn. These values are in agreement with Boss and Bowman (1996a), which also reported higher NE_m and NE_g values for barley over corn. No differences ($P > .10$) were seen in diet digestibility, or estimated grain energy value between barley varieties. No differences ($P > .10$) in in vivo digestion were seen when MIX was compared to GUN and HAR.

Table 3. In vivo digestion of finishing diets containing corn, Gunhilde barley (GUN), Harrington barley (HAR), or 50% Gunhilde + 50% Harrington barley (MIX) as basal grains.

Item	Corn	GUN	HAR	MIX	SE	<i>P</i>		
						corn vs barley ^a	GUN vs HAR ^b	GUN/HAR vs MIX ^c
Fecal output, kg/d								
DM	4.65	1.80	2.90	3.09	.286	.0004	.02	.07
Starch	874.9	36.0	160.8	89.7	69.62	.0001	.21	.92
In vivo digestibility, %								
DM	64.05	83.80	74.41	73.41	2.284	.001	.01	.08
Starch	86.02	99.13	96.62	98.07	1.194	.0001	.15	.90
Digestible intake, kg/d								
DM	8.36	9.32	8.43	8.56	.318	.32	.06	.45
Starch	5.43	4.08	4.58	4.62	.115	.0001	.01	.08
Grain NE_m , Mcal/kg	2.05	2.14	2.19	2.13	.046	.09	.49	.54
Grain NE_g , Mcal/kg	1.39	1.47	1.51	1.46	.040	.09	.49	.53

^aComparison of corn vs barley.

^bComparison of Gunhilde and Harrington barley.

^cComparison of Gunhilde and Harrington barley vs MIX.

Hot carcass weight was 17.5 kg heavier ($P = .03$) for corn-fed steers than for steers fed barley (Table 4). This agrees with Boss and Bowman (1996a) and Milner et al. (1995) whose corn-fed steer hot carcass weights were heavier (16.0 kg on both trials) than those fed barley. Boss and Bowman (1996a) also reported that HAR-fed steers had hot carcass weights 12.4 kg heavier than those steers fed GUN or Medallion barley. On this trial we observed no difference ($P > .10$) in hot carcass weight when HAR was compared to GUN or when MIX was compared to GUN and HAR.

Carcasses from corn-fed steers had greater ($P = .004$) %KPH compared to barley-fed steers, although there were no differences between MIX and GUN or HAR. Carcasses from steers fed HAR had greater ($P = .0006$) %KPH than steers fed GUN. No effect ($P > .10$) of diet was seen on backfat thickness, ribeye area, marbling score, yield grade, or quality grade. These results are in agreement with Ovenell-Roy et al. (1998a), Bradshaw et al. (1992), and Milner et al. (1995) who reported that no differences ($P > .10$) in marbling score, yield grade, or quality grade occurred due to barley variety. However, Milner et al. (1995) did find that steers fed Steptoe barley had greater ($P > .05$) ribeye area than those steers fed either HAR or Morex barley. Ovenell-Roy et al. (1998a) also reported differences ($P < .05$) in steer hot carcass weight, backfat, ribeye area, and %KPH when comparing six barley varieties. Further, Boss and Bowman (1996a) found that HAR fed steers had greater ($P = .06$) marbling scores and carcass quality grades than steers fed GUN, Medallion, or corn.

They also reported that corn and HAR had greater ($P = .003$) yield grades than steers fed GUN or MED. Ovenell-Roy et al. (1998a) and Bradshaw et al. (1996) reported no meaningful differences in carcass characteristics between barley varieties compared.

Table 4. Carcass characteristics of steers fed finishing diets containing corn, Gunhilde barley (GUN), Harrington barley (HAR), or 50% Gunhilde + 50% Harrington barley (MIX) as basal grains.

Item	Corn	GUN	HAR	MIX	SE	<i>P</i>		
						corn vs barley ^a	GUN vs HAR ^b	GUN/HAR vs MIX ^c
No. of steers	20	20	20	20				
Hot carcass, kg	343.2	325.0	325.9	326.3	3.64	.03	.86	.86
Backfat, cm	1.28	1.31	1.22	1.44	.140	.86	.57	.27
Ribeye area, cm ²	76.3	79.7	78.9	78.9	1.67	.37	.68	.81
KHP fat, %	2.88	1.87	2.49	2.07	.097	.004	.0006	.30
Marbling score	5.3	4.6	4.7	4.8	.20	.15	.59	.49
	(Mod30)	(Sm 60)	(Sm 70)	(Sm 80)				
Yield grade	3.3	3.0	3.0	3.2	.17	.44	.67	.36
Quality grade	13.0	12.1	12.2	12.2	.25	.10	.80	.81
	(Ch ⁰)	(Ch ⁻)	(Ch ⁻)	(Ch ⁻)				

^aComparison of corn vs barley.

^bComparison of Gunhilde and Harrington barley.

^cComparison of Gunhilde and Harrington barley vs MIX.

Implications

Steers fed Harrington, a malting barley variety, performed similarly to those fed Gunhilde, a feed barley. Feeding a combination of Gunhilde and Harrington barley showed no associative effects on animal performance. Previous research has shown variation in composition of barley varieties from year to year and when grown under different environmental conditions (Bradshaw et al., 1992 and Kemalyan et al., 1989). This could explain the

differences reported in animal performance between barley varieties by Boss and Bowman (1996a and b) and our trial. Ovenell-Roy et al. (1998a) alluded in their discussion that a year-to-year variation between the barley varieties fed could have accounted for differences in animal performance.

Lack of differences in carcass characteristics on this trial could be attributed to number of days on feed rather than basal grain variety. Identification of factors causing differences in feed values of the different barley cultivars could lead to the development of varieties having consistent animal performance.

CHAPTER 4

RUMINAL DIGESTION BY STEERS FED HIGH CONCENTRATE DIETS
CONTAINING CORN OR BARLEYIntroduction

Suited to the semi-arid growing conditions of the Great Northern Plains and Pacific Northwest region, barley is a major cash crop for the region. Wide availability has allowed area livestock producers to utilize barley in many aspects of their feeding programs. However, with a number of varieties on the market less is known about the feeding quality of individual cultivars than about malting quality. Classification of these cultivars, whether of a feeding or malting type, is typically based on malting characteristics rather than actual feeding value (Gibson et al., 1994).

Characterized by a fast rate of ruminal fermentation, barley varieties have demonstrated a wide range of performance differences in feeding as well as metabolism trials. Boss and Bowman (1996a) reported steers fed Harrington had higher ADG and DM intakes when compared to steers fed Gunhilde. These differences may be attributed to rate and /or site of starch utilization by the ruminant animal. Surber and Bowman (1998) and Ørskov (1986) reported that more starch from corn escapes ruminal digestion than barley starch. Slow ruminal starch digestion has been reported to be desirable for animal

performance (Tyrrell and Moe, 1974). Our objectives were to evaluate ruminal digestion characteristics of corn and barley concentrate diets, and to determine if associative effects resulted from feeding a malting barley variety in combination with a feed barley.

Materials and Methods

Four ruminally and duodenally cannulated steers (Hereford/Angus average wt 635 kg) were used in a 4 X 4 Latin square design to evaluate site, rate, and extent of digestion of corn and barley high concentrate diets. Diets compared were: 1) corn, used as a control; 2) Gunhilde, a six-row European feed grade barley (GUN); 3) Harrington, a two-row malting barley (HAR); or 4) 50% Gunhilde/50% Harrington (MIX). Steers were housed in individual concrete floored pens (15 m²). Diets were balanced to be isonitrogenous (13.5% CP) and isocaloric (1.93 Mcal/kg NE_m, 1.28 Mcal/kg NE_g). Diet compositions are presented in Table 1 and are identical to those used in the feedlot trial. Diets were hand mixed and limit fed at 10.9 kg/d, with half fed at 0800, and the other half fed at 1800. Water was available free choice throughout the metabolism trial. Pens were cleaned and bedded with straw at the beginning of each period.

Grains were coarsely cracked through a Denver, Inc. hammer mill during the feedlot trial and stored in nylon grain storage sacks until the start of the metabolism trial. Oatlage for the metabolism trial was obtained from the same

bag used for the feedlot trial. During the metabolism trial, oatlage was stored in tight sealing [50 gal] Rubbermaid trashcans and used as needed.

Cannulated steers used in the experiment were contemporaries to those used in the feedlot trial. These steers were fitted with permanent ruminal and T-type duodenal cannulas (trial protocol approved by Montana State University Animal Care and Use Committee). Montana State University Research Staff and graduate students performed ruminal cannulations. Dr. Bruce Sorenson, attending veterinarian, performed duodenal cannulations. Surgeries were performed at Livestock Teaching and Research Center in Bozeman, MT in the Spring of 1995.

Each trial period consisted of 21 d. Fourteen days for diet adaptation followed by a 7-d collection period. Diet changes between periods were done using a step-wise substitution of 25% of the new ration to the total as-fed diet per day over the first 4 d. Feed grab samples were taken at each feeding during the collection period, composited, and ground through a 1-mm screen in a Wiley mill for analyzed of DM, OM, N, starch (AOAC, 1997), and ADF (Van Soest et al., 1991).

On day seven of the adaptation period, sustained release boluses (Captec Chrome, Nufarm, Auckland, New Zealand) were placed in the rumen of each steer. This administered chromium sesquioxide as an external marker to estimate DM flow to the duodenum and fecal output. A release rate of 1.0198 g/d Cr was calculated by multiplying the percent of Cr in chromium sesquioxide (.6842) by the mean release rate supplied by the manufacturer (1.49 g/d). Steers

were pulse dosed 300 g of their respective grains which had been labeled with Yb (Poore et al., 1991) into the rumen at the first feeding of the collection period (time 0 h) as a digestion kinetics marker. Duodenal and fecal grab samples were taken at 0, 3, 6, 9, 12, 15, 18, 21, 24, 30, 36, 42, 48, 54, 60, and 72 h after dosing.

Fecal samples were dried at 60°C for 72 h in a forced-air oven, and then ground through a 1-mm screen in a Wiley mill. A portion of hourly fecal samples was composited on a DM basis within steer and period. Composited fecal samples were analyzed for DM, OM, N, ADF, starch, and Cr (Hill and Anderson, 1958). A portion of each hourly duodenal samples was dried at 60°C in a forced-air oven for 72 h, ground in a mortar and pestle, further ground in a Udy mill and composited within steer and period. These samples were analyzed for DM, OM, N, ADF, Cr, starch and purine content (Zinn and Owens, 1986).

Half of the remaining portion of the hourly duodenal was used for VFA analysis, the other used for ammonia analysis (AOAC, 1997). Hourly dried duodenal, hourly dried fecal, and Yb-labeled grain samples were analyzed for Yb content (Poore et al., 1991) by a ICP-ES (Fison Instrument Accuris) with a wave length of 369.42 μm (Fassel, 1978). Hourly duodenal Yb concentrations were fitted into a one-compartment model to estimate particulate flow rate, retention time, time delay (Tau) and DM output (Ellis et al., 1979). On the final day of the collection period, 1.5 L/steer of rumen fluid was collected from each steer. Raw fluid was filtered through four layers of cheesecloth into a different 2000 ml flask.

Differential centrifugation (Smith and McAllen, 1974) was used to extract a microbial pellet, which was then analyzed for DM, N (AOAC, 1997), and purine content (Zinn and Owens, 1986).

On day four of the collection period at 0800, duplicate nylon bags plus one blank per set (total 36 bags) were placed in the rumen (time 0 h). Nylon bags (Ankom, Spencerport, NY) contained 5 g of the respective grain source fed to each steer. This grain was processed identically to that of the feedlot trial. Bags were 10 cm X 20 cm with a pore size of 50 μ m, and were removed from rumen after incubation periods of 0, 2, 4, 6, 9, 12, 15, 18, 21, 24, 30, and 36h. Rumen fluid pH was also measured at these times. Once removed from the rumen, bags were washed in cold water by hand until water ran clearly through them. They were then placed in a 60°C forced-air oven for 54 h. Bag residues were analyzed for starch, with in situ rate and extent of starch and DM disappearance calculated (Bowman and Firkins, 1993).

Data were analyzed as a 4 X 4 Latin square design using the GLM procedure of SAS (1993). Planned comparisons were made for: corn vs barley, GUN vs HAR, and MIX vs GUN and HAR. Treatment least square means were separated by the LSD method of SAS (1993) if treatment F-test was significant ($P < .10$). Least square means and associated standard errors are reported

Results and Discussion

Diet nutrient analysis is presented in Table 1. Organic matter and starch content were higher for the corn diet (94.17 and 48.4%) compared to the barley diets (average 93.12 and 39.76% respectively). Ovenell-Roy et al. (1998a and 1998b) compared six barley cultivars in two feed trials. One of the cultivars in each trial was Harrington. In their first trial, nutrient analysis of grains found HAR had starch and CP values (52.4 and 10.4% of OM) similar to the six varieties examined. In the second trial, HAR supplied the second highest amount of CP (11.2% of OM) of the six barleys studied behind Camelot barley, which supplied 15.0%. Starch content of HAR was 62.5% of OM in the second trial. Interestingly, all of the barleys grown for the trial were grown in the same year under the same conditions in the Pullman, WA-Moscow, ID area.

No differences ($P > .10$) were seen in DM intake when corn was compared to barley or when GUN was compared to HAR (Table 5). The average DM intake of GUN and HAR, however, was greater ($P = .05$) than MIX-fed steers (average 9899.5 and 9846 g/d, respectively). Comparison of GUN vs HAR and GUN/HAR vs MIX were not different ($P > .10$) for starch intake. Starch intake was greater ($P = .006$) for corn-fed steers than for barley-fed steers. With the corn diet providing more starch, steers fed corn consumed 861 g/d of starch more when compared to the barleys. This large difference in amount of supplied starch between corn and barley grain sources is repeated in literature but not to the extent seen in this trial. Boss and Bowman (1996b), in a similar trial, observed a

greater amount of starch intake from a corn-based diet as compared to barley, though the difference was not significant. Surber and Bowman (1998), also in a restricted intake study, saw corn fed steers consume 292 g/d more starch than steers fed barley.

In the Boss and Bowman (1996b) trial, HAR steers consumed 17 g/d less N than those steers fed corn, GUN, or Medallion barley. Results of this study found HAR fed steers with greater ($P = .01$) N intake than GUN steers (238 vs 228 g/d), and the average of the barley-fed steers (231 g/d) was greater ($P = .0003$) than corn-fed steers (213 g/d). The MIX diet had lower ($P = .04$) N intake than the average of GUN and HAR (226 vs 233 g/d). Since both GUN and MIX diets supplied nearly the same amount of N, this difference may be attributed to the fact that the HAR diet supplied more CP and therefore greater N to the steers.

Table 5. Characteristics of digestion in steers fed finishing diets of corn, Gunhilde barley (GUN), Harrington barley (HAR), and 50% Gunhilde + 50% Harrington (MIX) as basal grains.

Item	Corn	GUN	HAR	MIX	SE	<i>P</i>		
						corn vs barley ^a	GUN vs HAR ^b	GUN/HAR vs MIX ^c
Intake, g/d								
DM	9886	9912	9887	9846	.018	.84	.36	.05
Starch	4792	3793	4016	3983	.177	.006	.41	.73
N	213	228	238	226	.002	.0003	.01	.04
Flow to duodenum, g/d								
DM	4830	4295	4882	4665	.152	.26	.03	.70
Starch	1167	389	690	567	.119	.004	.12	.86
Total N	169	168	183	175	.004	.24	.04	1.0
NH ₃ N	9.93	11.50	12.06	11.15	.615	.06	.54	.43
Nonammonia N	159.20	156.12	171.19	164.29	3.77	.33	.03	.90
Microbial N	51.50	61.31	61.40	53.71	4.73	.23	.99	.23
Feed N	107.70	94.81	109.80	110.58	6.12	.72	.13	.31
Ruminal digestion, %								
DM	51.16	56.66	50.62	52.62	1.59	.29	.04	.62
Starch	75.64	89.79	82.79	85.63	2.92	.02	.14	.86
Feed N	49.61	58.34	53.93	51.09	2.58	.16	.27	.16
Total N	20.67	26.34	23.10	22.43	1.71	.15	.23	.32
Microbial efficiency, g of N/kg of OM truly digested in rumen	10.61	10.90	12.33	10.19	.81	.59	.26	.19
Post-ruminal digestion, %								
DM	32.63	39.56	41.56	34.93	2.04	.04	.51	.07
Starch	45.17	77.64	63.56	70.31	5.63	.008	.13	.97
N	57.06	65.81	65.17	59.97	1.46	.008	.77	.02
Total tract digestion, %								
DM	67.68	73.80	71.10	69.19	1.08	.03	.13	.05
Starch	88.10	97.73	93.53	95.92	1.13	.001	.04	.84
N	66.09	74.87	73.31	69.00	.97	.001	.30	.005
Duodenal, one-compartment model								
Tau, h	8.04	3.01	5.41	2.86	.83	.004	.09	.23
Flow rate, h ⁻¹	.04	.03	.06	.04	.005	.48	.007	.32
Retention time, h	39.70	43.18	27.26	36.62	2.40	.20	.003	.65
Fill, kg	33.71	32.68	43.18	46.11	6.43	.39	.29	.34

^aComparison of corn vs barley.

^bComparison of Gunhilde and Harrington barley.

^cComparison of Gunhilde and Harrington barley vs MIX.

No associative effects ($P > .10$) were seen in nutrient flow to the duodenum (Table 5). Corn fed steers had greater ($P = .004$) starch flow to the duodenum than steers fed barley (1167 vs 549 g/d avg, respectively). This was

due to lower ($P = .02$) ruminal starch digestion by steers fed corn than those fed barley (75.64 vs 86.07% avg, respectively).

These results are in agreement with Ørskov (1986) and Feng et al. (1995) who reported corn had a slower rate of ruminal starch digestion than barley. Ørskov (1986) stated that up to 90% of starch from whole or processed barley may be lost to ruminal fermentation and suggested that on occasion, up to 40% of corn starch could escape ruminal fermentation. This rate of degradation seems to be reduced if there is a roughage source in the diet. Boss and Bowman (1996b) reported corn and barley had similar digestion rates. In their study GUN had lower ($P = .04$) ruminal DM digestion than HAR, resulting in more ($P = .03$) DM flowing to the duodenum (4895 vs 4882 g/d, respectively). In our study, daily starch flow, though not significant ($P = .12$), was over 300 g/d greater for steers fed HAR barley than for steers fed GUN barley (690 vs 389 g/d, respectively). This could be due to a greater percent of starch provided by the HAR diet and subsequently greater starch intake by the steers of this treatment.

Steers fed HAR had greater ($P = .04$) total N and non-ammonia N ($P = .03$) passage to the duodenum than GUN. Steers fed HAR had greater ($P = .04$) N flow to the duodenum than steers fed GUN, which can again be related back to the fact that more N was supplied by the diet. Feng et al. (1995) found total N, microbial N, and non-ammonia N flow to the duodenum greater for barley than for corn. These results agreed with Spicer et al. (1982) who reported that with increased ruminal starch digestion, microbial N flow to the intestines will also increase. Results of our study support this theory. An increase in amount of

starch digested in the rumen, expressed as a percentage for each treatment, reflected the increase in microbial N flow to the duodenum. There were no differences ($P > .10$) observed between corn or barley diets in total N, non-ammonia N, microbial N or feed N flow to the duodenum in this study. Our results are similar to those of Surber and Bowman (1998) who found no differences between corn or barley diets in total N, NH_3N , non-ammonia N, and feed N flow to the abomasum. Boss and Bowman (1996b) found a corn diet had greater ($P = .01$) feed N (29 g/d) flowing to the abomasum than the average of three barley diets (average 17 g/d). Zinn et al. (1996) in studying feeding values of hulless and covered barley, found flaked corn had less ($P = .01$) microbial N flow to the duodenum than rolled or flaked barley of either the hulless or covered variety. Like Boss and Bowman (1996b), this resulted in lower ruminal degradation of feed N for corn vs barley ($P = .05$). A similar result was not observed in our trial.

No associative effect ($P > .10$) in ruminal digestion from feeding a malt and feed barley in combination was observed. The average of the barleys did have greater ($P = .02$) ruminal starch digestion than corn (average 86.07 vs 75.64%, respectively). Ruminal DM digestion of GUN (56.66%) was greater ($P = .04$) than that of HAR (50.62%). No other differences were detected in ruminal nutrient digestion ($P > .10$).

Microbial efficiency (g of N/kg of OM truly digested in rumen) were not different ($P > .10$) for any of the comparisons. This agrees with Surber and

Bowman (1998) but not with Boss and Bowman (1996b) or Zinn et al. (1996) who both reported corn having lower microbial efficiency ($P = .01$) than barley diets.

Post-ruminal digestion of DM, starch, and N was greater ($P < .04$) for barley than for corn. Boss and Bowman (1996b) found post-ruminal starch digestion of corn (41.8%) lower than that of barley (82.0%). Surber and Bowman (1998) reported similar results with corn having 55.4% and barley 90.3% post-ruminal starch digestibility. In Zinn et al. (1996), no difference in post-ruminal starch digestion was detected between corn or barley. They did report an interaction between barley variety and type of processing for post-ruminal digestion. Steam flaking of barley increased post-ruminal digestion of starch as well as N, findings that agreed with results from an earlier trial (Zinn, 1993). In the comparison of GUN vs HAR, there were no ($P = .10$) differences in post-ruminal digestion. Gunhilde and HAR had greater ($P = .02$) post-ruminal N digestion than MIX (average 65.49% and 59.97%, respectively). No associative effects ($P > .10$) were observed in post-ruminal digestion of DM and starch. When compared to MIX, GUN/HAR had greater ($P = .02$) post-ruminal digestion of N (59.97 vs 65.49% average).

Feng et al. (1995) reported corn having lower total tract DM and starch digestion than barley. They did not find any differences between barley varieties. In a study comparing six barley varieties, Ovenell-Roy et al. (1998a) found no differences between varieties in total tract starch digestion. In our study, GUN had greater ($P = .04$) total tract starch digestion than HAR. Corn-fed steers had lower ($P < .03$) DM, starch, and N total tract digestion than did steers fed barley.

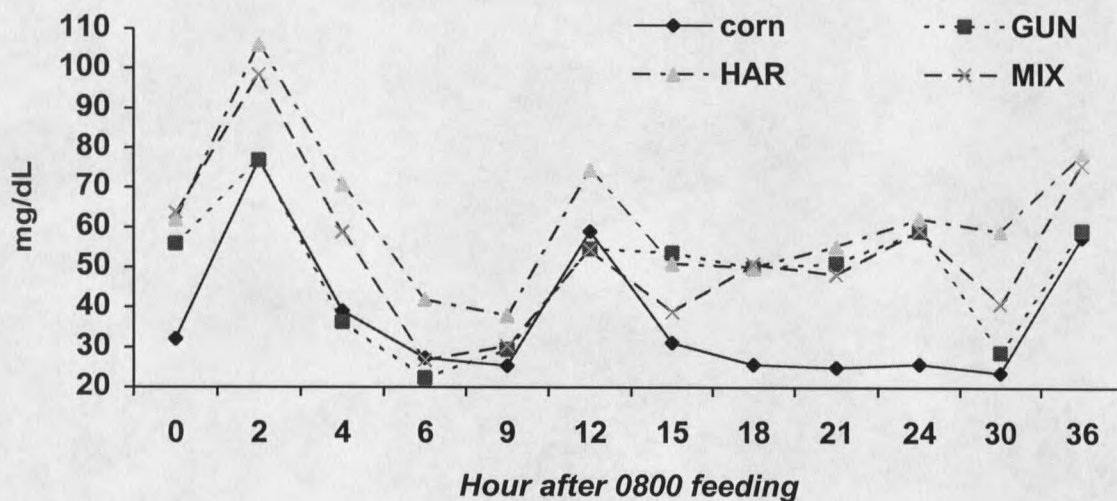
Nutrient flow to the duodenum and ruminal digestion were not different ($P > .10$) for MIX when compared to GUN and HAR. Post-ruminal and total tract digestion of N was less ($P < .02$) for MIX than for GUN and HAR.

To estimate flow rates of the diet, a one-compartment model and sampling at the duodenum was used. No differences ($P > .10$) were detected in particulate flow rate or retention time between corn or barley diets or when MIX was compared to GUN/HAR. However, HAR had lower ($P = .003$) retention time than GUN (27.26 vs 43.18 h, respectively) resulting in a greater ($P = .007$) flow rate (.06 vs .03 h⁻¹, respectively) to the duodenum. Tau for corn was greater ($P = .004$) by 4.5 h than GUN, HAR, and MIX. This is very similar to the 3.5 h difference that Boss and Bowman (1996b) reported. No differences ($P > .10$) were seen between the four diets in fill (average 38.92 kg).

Figure 1 presents ruminal NH₃N concentrations plotted against time. No treatment by sampling time interaction was observed ($P = .5$) for ruminal NH₃N concentration. Average of barley diets ruminal NH₃N concentration was greater ($P = .0001$) when compared to corn (average 5.48 vs 3.74 mg/dL, respectively). Harrington also had a higher NH₃N level (6.25 mg/dL) when compared to GUN (4.81 mg/dL; $P = .001$). There were no differences detected ($P = .6$) when MIX was compared to GUN/HAR. Ruminal NH₃N concentrations for this trial ranged from 2.23 to 10.59 mg/dL. The lower values observed on this trial are slightly lower than the ammonia N concentration values of 3.3 and 8.5 mg/dL that Kang-Merzharich and Broderick (1981) reported as being required for maximum ruminal microbial growth. This may be the case, as microbial efficiency (g of

N/kg) values on this trial were lower than those reported by Boss and Bowman (1996b) and Surber and Bowman (1998) under similar circumstances. Urea was added to the four diets (Table 1) in order to balance nitrogen levels. As can be seen, the corn diet had a larger percent of this non-protein nitrogen source included.

Figure 1. Ruminal fluid ammonia concentration of steers fed finishing diets of corn, Gunhilde barley (GUN), Harrington barley (HAR), and 50% Gunhilde + 50% Harrington (MIX) as basal grains.



Comparison of treatment x hour ($P = .5$).

Comparison of corn vs barley ($P = .0001$).

Comparison of Gunhilde vs Harrington ($P = .0001$).

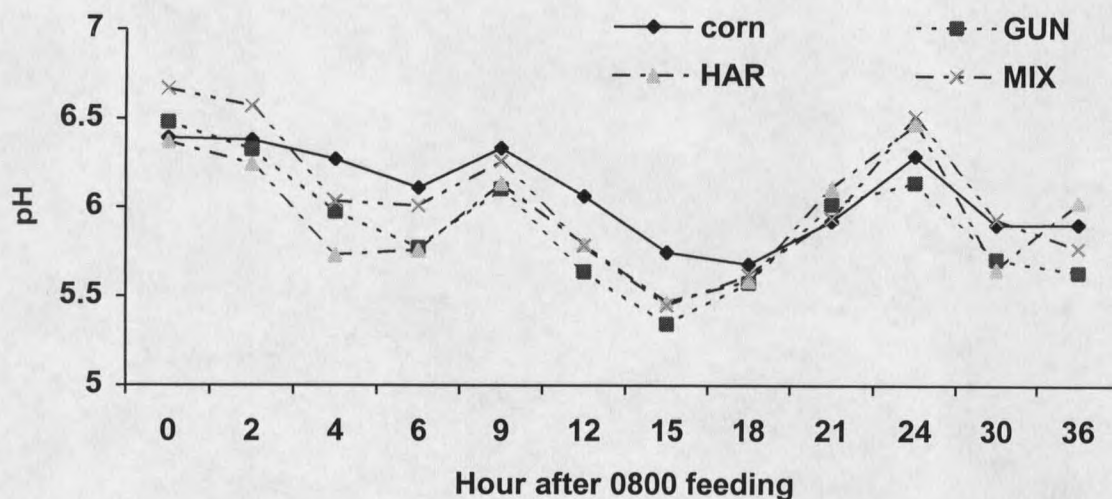
Comparison of Gunhilde and Harrington vs MIX ($P = .6$).

Ruminal pH means are plotted against sampling time and presented in Figure 2. There was no treatment by sample time interaction ($P = .3$). Comparison of GUN vs HAR ($P = .5$) showed no differences in ruminal pH. Average ruminal pH for corn (6.08) was higher ($P = .005$) than the average of the

barley diets (5.97). This agrees with the findings of Boss and Bowman (1996b) and Surber and Bowman (1998). As in these two studies the slower rate of ruminal DM and starch digestion of the corn diet on this trial resulted in a higher pH value than for the barley diets. A higher pH ($P = .007$) was observed for MIX when compared to GUN and HAR (6.05 vs 5.93 average, respectively). A possible reason for this could be the lower ($P = .0001$) concentration rate of acetate and isovalerate, greater ($P = .0001$) concentration of propionate, and the absorption rate of these VFA in the MIX when compared to GUN and HAR. Church (1998) states that rumen pH can be stabilized by VFA absorption. With absorption increasing as pH decreases. This is a result of an increase in ruminal papillae size (i.e. greater pH absorption surface area).

A main concern with feeding high concentrate barley diets is the associated decrease in ruminal pH and resulting feeding disorders, such as acidosis and bloat. With average ruminal pH of animals on high concentrate diets ranging from 5.5 to 6.5 (Church, 1988), it is important to maintain a constant pH level to maintain a high level of animal metabolic performance. Evidence of this can be found in reports of corn based diets such as those reported here and by Boss and Bowman (1996b). These trial seem to indicate that corn diets remain at a fairly constant pH level when compared to barley diets. Church (1988) reports that as acidity decreases, so does cellulolytic fora activity. Conversely, amylolytic activity will increasing. Less fluctuation in ruminal pH will result in fewer changes in the microflora population, and subsequently fewer feeding disorders, leading to better animal performance.

Figure 2. Ruminal fluid pH of steers fed finishing diets of corn, Gunhilde barley (GUN), Harrington barley (HAR), and 50% Gunhilde + 50% Harrington (MIX) as basal grains.



Comparison of treatment vs hour ($P = .3$).

Comparison of corn vs barley ($P = .005$).

Comparison of Gunhilde vs Harrington ($P = .5$).

Comparison of Gunhilde and Harrington vs MIX ($P = .007$).

No interactions for treatment by sampling time ($P > .1$) were detected for ruminal VFA concentrations, so averages across time are presented in Table 8.

Table 6. Ruminal volatile fatty acids of steers fed finishing diets of corn, Gunhilde barley (GUN), Harrington barley (HAR), and 50% Gunhilde + 50% Harrington (MIX) as basal grains.

Item	Corn	GUN	HAR	MIX	SE	<i>P</i>		
						corn vs barley ^a	GUN vs HAR ^b	GUN/HAR vs MIX ^c
Total VFA, mM	55.03	61.95	57.28	60.36	.893	.0001	.0003	.49
VFA, mol/100 mol								
Acetate	54.22	52.96	54.07	52.25	.202	.0001	.0002	.0001
Propionate	24.65	25.02	24.15	27.08	.418	.11	.14	.0001
Isobutyrate	1.24	1.31	1.33	1.29	.019	.002	.53	.25
Butyrate	14.68	15.05	14.85	14.32	.284	.85	.63	.07
Isovalerate	3.71	3.49	3.40	2.94	.091	.0001	.49	.0001
Valerate	1.51	2.20	2.21	2.12	.037	.0001	.83	.08
Acetate:propionate ratio	2.25	2.30	2.28	2.08	.042	.53	.75	.0001

^aComparison of corn vs barley.

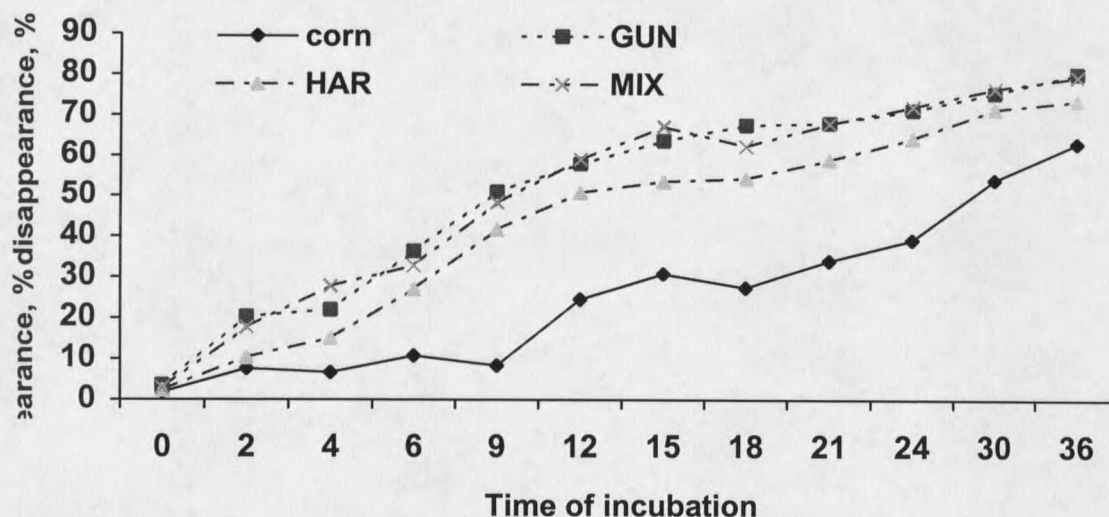
^bComparison of Gunhilde and Harrington barley.

^cComparison of Gunhilde and Harrington barley vs MIX.

Corn-fed steers had lower ($P = .0001$) total VFA concentration respectively (55.03 vs 59.86 mM average, respectively) than steers fed barley. GUN-fed steers had the highest total VFA concentration (61.95 mM) of the four diets, and a significantly higher ($P = .003$) concentration than HAR-fed steers (57.28 mM). Boss and Bowman (1996b) conversely found HAR-fed steers to have greater ($P < .10$) total VFA concentration than GUN-fed steers (77.4 vs 72.7 mM). Isobutyrate and valerate percentages were also lower ($P < .002$) for steers fed corn as compared to steers fed barley. Corn fed steers had higher ($P = .0001$) acetate and isovalerate percentages than barley fed steers. Acetate percentage was lower ($P = .0002$) for GUN than for HAR. Associative effects were observed in acetate, propionate, and isovalerate percentages, and acetate:propionate ratio. An associative effect was observed in acetate:propionate ratio with MIX being lower ($P = .001$) when compared to the average of GUN and HAR.

Boss and Bowman (1996b) and Surber and Bowman (1998) reported lower acetate:propionate ratio for steers fed corn as compared to steers fed barley. In the formerly mentioned paper there is speculation that an increase in ADG of corn-fed steers could be due to greater availability of gluconeogenic precursors. Our trial also found acetate:propionate ratio lower for corn than barleys though not significant ($P > .10$). It is important to point out two facts from our trial on this point. First, our ADG from the feedlot trial for corn when compared to barleys though greater, was not as pronounced as the Boss and Bowman (1996a) findings ($P = .06$ vs $P = .002$). Secondly, though not compared statistically, the acetate:propionate ratio for MIX was 0.166 m/M less than corn. Interestingly MIX had the highest ADG of the barley diets in the feedlot trial though the difference was not significant ($P > .10$).

Figure 3. In situ dry matter disappearance of steers fed finishing diets of corn, Gunhilde barley (GUN), Harrington barley (HAR), and 50% Gunhilde + 50% Harrington (MIX) as basal grains.



Pooled SEM was 2.73%.

In situ DM disappearance (ISDMD) of the four diet grains is presented in Figure 3. Corn had lower ($P < .003$) ISDMD when compared to the barleys after hour 4. Harrington had less ($P < .05$) ISDMD than GUN at 2, 6, 15, 18, and 21 h of incubation. Only at hours 4 and 15 were any differences seen when MIX was compared to GUN and HAR. Here MIX had greater ($P < .05$) incubation than did GUN and HAR. These results agree with Boss and Bowman (1996b) who also found corn with lower ISDMD when compared to barley.

Implications

Harrington barley-fed steers had lower retention time and therefore greater flow rate than Gunhilde-fed steers. This did not translate into any benefits for site of digestion or amount of total tract digestion of dry matter, starch, or nitrogen when barleys were compared. Though not compared to corn, Gunhilde duodenal retention time was higher by three and one half-hours.

Feeding a combination of malting variety and feed variety barley did result in some interesting findings. Differences in volatile fatty acid concentrations and absorption rate of 50% Gunhilde and 50% Harrington as compared to Gunhilde and Harrington may have helped to control ruminal pH. This along with a lower acetate:propionate ratio may result in an increase in animal performance. Harrington barley had greater microbial efficiency. Fifty-percent Gunhilde/ 50% Harrington had greater total tract nitrogen digestion when compared to Gunhilde and Harrington.

CHAPTER 5

CONCLUSIONS

Results of this trial agree with Boss and Bowman (1996a) that barley diets with fast rates of ruminal digestion may not hinder animal performance. They found that over the course of their trial, corn-fed steers had greater average daily gains and final weights. Our results echoed these findings. Comparisons of carcass characteristics of steers fed corn and barley were similar. This could be attributed to number of days on feed. We also confirmed the Surber and Bowman (1998) findings that starch digestibility percent is greater for barley than for corn and that digestible starch intake is higher for corn than for barley. Monitoring the feeding of barley in high concentration diets is a must due to its fast rate of fermentation and subsequent digestive disorders. Yet taking into consideration feed cost and cost of gain, barley at \$.35/d and \$.15/kg less than corn along with its higher regional availability, make it the economical common sense choice.

We found corn to have a slower rate of ruminal fermentation when compared to barley, as well as a greater amount of starch reaching the lower tract for further digestion. Our findings are consistent with the literature as to site and rate of nutrient digestion of corn when compared to barley. When barley varieties were compared, though not significant, Harrington supplied 301 g/d of Starch more to the duodenum than did Gunhilde. Harrington was higher in total

and non-ammonia nitrogen flow to the duodenum as well. Total tract digestion and duodenal retention time favored Gunhilde over the other diets.

Few associative effects were observed. The most promising was the volatile fatty acid concentration and absorption rate differences seen in the MIX diet. This may have lead to a higher rumen pH level translating into better animal performance.

Though we did not see the slower rate of ruminal starch digestion of Gunhilde compared to Harrington that was observed in the Boss and Bowman (1996a and b) trials, our result on barley performance compared to corn are encouraging. Our results reaffirm the theory that barley feed values differ within variety and from year to year. A consistent malting variety has been established with the Morex cultivar being the standard. However, further research into identifying what causes differences in feed value of barley cultivars will lead to the development of consistent performance varieties.

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APPENDIX A

ANALYSIS OF VARIANCE TABLES

Table 7. Analysis of variance for feedlot trial comparing finishing diets of corn, Gunhilde barley (GUN), Harrington barley (HAR), and 50% Gunhilde + 50% Harrington (MIX) as basal grains.

Source	Degrees of Freedom
Block	1
Treatment	3
B X T	3
Error	8
Total	15

Table 8. Analysis of variance for metabolism trial comparing finishing diets of corn, Gunhilde barley (GUN), Harrington barley (HAR), and 50% Gunhilde + 50% Harrington (MIX) as basal grains.

Source	Degrees of Freedom
Animal	3
Period	3
Treatment	3
Error	6
Total	15

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