Feed quality of two recombinant inbred barley lines, LB6 and LB57, from a Lewis x Baronesse cross
by Travis Craig Blackhurst

A thesis submitted in partial fulfillment of the requirement for the degree of Master of Science in Animal and Range Sciences
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Abstract:
The objectives of this study were to evaluate feedlot performance, nutrient digestion, and carcass characteristics of steers fed two experimental barley lines, LB6 and LB57, developed by crossing Baronesse (2-row, feed type) and Lewis (2-row, feed and malting type). Eighty crossbred steers (avg initial wt 374 kg) were allotted to 16 pens in a randomized complete block design. During the 159-d feeding trial steers consumed an 83% barley diet based on: 1) Baronesse; 2) Lewis; 3) LB6; or 4) LB57. All diets were formulated to contain 13% CP. Steers were weighed, and diet, ort, and fecal samples collected every 28 d. Acid insoluble ash was used as an internal marker to estimate fecal output. Steers were slaughtered when 70% were visually estimated to grade Choice.

Data were analyzed by the GLM procedure of SAS to detect treatment differences with pen as the experimental unit. Planned comparisons were made between LB6 and the mean of Baronesse and Lewis, and between LB57 and the mean of Baronesse and Lewis. No differences (P >0.10) were found in ADG between barley lines (avg 1.5 kg/d). No differences (P >0.10) were found between LB57 and the parent varieties in DMI, DM digestibility (DMD), starch digestibility or feed efficiency (kg gain/100 kg feed). Dry matter intake was 4.7% greater (P = 0.004) by steers fed Baronesse and Lewis than by steers fed LB6 (avg 8.9 vs ,8.5 kg/d). Feed efficiency was 5.4% higher (P = 0.06) for steers fed LB6, than steers fed parent lines (18.0 vs avg 17.1, respectively). The LB6 fed steers had greater (P = 0.03) in vivo DMD than steers fed the parent lines (74.7 vs avg 73.2%). Steers fed LB6 had lower (P = 0.06) marbling scores (small 40 vs avg small 75) than steers fed parent lines. No other differences (P > 0.10) were found in carcass traits. Results indicate that experimental barley line LB6 had improved feed efficiency and in vivo DMD compared with the parent cultivars, Baronesse and Lewis.

FEED QUALITY OF TWO RECOMBINANT INBRED BARLEY LINES, LB6 AND LB57, FROM A LEWIS X BARONESSE CROSS

by

TRAVIS CRAIG BLACKHURST

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APPROVAL

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Travis Craig Blackhurst

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.

Dr. Janice G. P. Bowman Janice Bowman (Signature) 10-3-00 Date

Approved for the Department of Animal and Range Science

Dr. Peter J. Burfening Peter Burfening (Signature) 10-3-00 Date

Approved for the College of Graduate Studies

Dr. Bruce R. McLeod Bruce R. McLeod (Signature) 11-17-00 Date

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ABSTRACT

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CHAPTER 1

INTRODUCTION

Importance of Barley and Cattle in Montana

Barley (*Hordeum vulgare* L.) is the world's fourth largest cereal crop in terms of production behind wheat, corn, and rice, and the fourth most important crop in the United States behind wheat, corn, and sorghum. While wheat and rice are used primarily for human consumption, and corn is used for both human consumption and for animal feed, barley is used primarily for animal feed or malt (Poehlman, 1985).

Barley belongs to the *Poaceae* family of grasses and is one of the oldest cultivated crops in the world. It has survived as a major cereal grain for three main reasons: 1) it has broad ecological adaptation, 2) it has use as feed grain for animals, and food consumption for humans, and 3) it is superior for malt used in brewing (Poehlman, 1985).

There are two major uses of barley in the United States. The largest use of barley is for animal feeds. Barley supplies primarily carbohydrate and some protein in a ration. Starch is the major source of carbohydrate in barley and can range from 36 to 58% (Bowman et al., 1997). Protein content can range from 10 to 15% depending on climate and soil conditions where the grain is grown (Poehlman, 1985). Most of the barley produced is used as feed for livestock (Bowman and Blake, 1997). The second largest use of barley is in the malting industry. Germinating seeds produce several enzymes, including, alpha-amylase and beta-amylase which hydrolyze starch and structural carbohydrates to dextrins and fermentable sugars (Poehlman, 1985). For malting barley preference is given to plump kernels, moderately low protein, and mealy rather than

glassy or steely endosperm. Another use for barley is human food. This makes up a small proportion of the total usage for barley in the United States, however, in some countries barley is used more as a human food source than for animal feed.

Barley can be divided into several general categories: two-rowed or six-rowed, winter or spring, and malting or feed cultivars. Two and six-row refer to the number of rows of kernels as one looks down on the head of the plant, and malting or non-malting refers to the malting characteristics.

Barley production is especially important in Montana. Montana is the second leading producer of barley in the United States, second only to North Dakota in total barley production. In 1999 barley sales accounted for 7% of Montana's total commodity receipts. This amounted to $123 million dollars in barley sales. Montana farmers planted 507,000 hectares to barley in 1999. A malting cultivar (Harrington) made up nearly 50% of the total ha's planted. Harrington is the most popular malting cultivar in Montana recommended by the American Malting Barley Association. Baronesse, a feed cultivar was second in total ha's planted with 7.6% of the total ha's planted in Baronesse barley. Baronesse is a German-developed two-row, rough-awned spring barley. It is noted for excellent irrigated yield potential and is highly resistant to lodging (Mt Ag Stat, 2000).

Montana is ranked 6th in the nation for number of beef cows with 1.58 million cows on Jan. 1, 2000. Last year Montana ranchers produced 1.57 million calves which ranked 7th in the United States. Income from cash receipts for livestock in 1999 was $865 million (Mt Ag Stat, 2000). Livestock plays an important role in Montana's economy, as does the grain industry. Logic would lead one to believe that when grain is

readily available and calves are so abundant there would be a large feedlot industry in close proximity. This however is not the case in Montana. Last year only 70,000 head of cattle were on feed in Montana. This includes steers, heifers, bulls, and cows. Over the past ten years the average is slightly higher at 86,000 head per year (Mt Ag Stat, 2000). However, considering that Montana ranchers produced 1.5 million calves in 1999, relatively few were fed out in Montana. Assuming that some of these animals were purebred breeding stock, and some were replacement heifers, there would still be at least 1 million calves produced for the feedlot industry.

If Montana could develop a feedlot industry, which would utilize both cattle, and grain grown in the state, income could be increased to both livestock and grain producers. This would be accomplished in part by reduced transportation costs of shipping both cattle and grain out of state. In addition, many jobs would be created with the inception of a large feedlot industry. Documenting the feed quality of both feed and malt barley could make it more attractive as a energy source in feedlot diets throughout the Pacific Northwest and southwest Canada, and could lead to increased economic value for livestock and grain producers.

CHAPTER 2

LITERATURE REVIEW

Advancements in Barley Breeding and Genetics

The genetic improvement of barley through breeding programs has made a major contribution to the production of food and fiber. New barley cultivars have improved agronomic characteristics, including higher yields per ha, expanded areas of adaptation, and reduced losses to environmental stresses and other pests such as weeds, disease, and insects (Larson, 1996). New developments in barley breeding will continue to increase food and fiber productivity. These advancements will come as a result of carefully planned breeding programs, which utilize scientific advances in many fields including plant genetics, and biotechnology.

The utilization of molecular genetic markers has greatly facilitated the identification of the genes that control quantitative traits (Botstein et al., 1980), referred to as quantitative trait loci (QTLs). Markers have been used for many years to identify regions on a chromosome that affect a given phenotypic trait. Genetic markers have allowed researchers to construct genetic maps for plants, animals, and humans. Molecular genetic markers being utilized include isozymes, restriction fragment length polymorphisms (RFLPs), random amplified polymorphic DNA (RAPDs; Poehlman and Sleper, 1995), and single locus polymerase chain reaction (PCR; Blake et al., 1998).

The barley cultivars utilized in this study were Baronesse, Lewis and two experimental lines from a Lewis x Baronesse cross. Both Baronesse and Lewis barley are grown extensively in the Pacific Northwest. These barley lines were chosen as parent

lines for a potential new barley genotype because of their individual strengths. Baronesse, as mentioned earlier, has extremely high irrigated yield potential, but has been found to have drought intolerance. Montana State University has utilized recent technology to identify three genes in Baronesse responsible for its high yield (Blake et al., 1998).

Lewis is a barley genotype developed in Montana from crossing Hector and Klages barley cultivars. It was developed and tested during the 70's and released for commercial production in 1985. Lewis yields more than parent variety Klages, and has similar yield to the high yielding Steptoe barley cultivar, but has better feed quality than Steptoe (Hockett et al., 1985). Lewis has similar malting quality as Klages barley, but is 3-d earlier in heading. Lewis shows more tolerance to spot and net blotch than Klages and is similar to Hector in tolerance to common root rot (Hockett et al., 1985).

Sixty recombinant inbred lines (RIL's) were developed from a Lewis x Baronesse cross. Testing all 60 RIL's in a feedlot study would be expensive and impractical. Therefore these 60 RIL's were catagorized based on several criteria. The RIL's were evaluated for agronomic performance based on yield and screened for the Baronesse high yield genes. They were also evaluated based on *in situ* dry matter digestibility (ISDMD). Malting quality was also measured on all the RIL's. From the 60 RIL's, eight were selected for preliminary feedlot trials (Blackhurst et al., 1999; Boss et al., 1999). From these eight we selected LB6 and LB57 for an extensive feedlot trial in Bozeman, Montana in 1999.

High Concentrate Feedlot Diets

Animals that are required to gain large amounts of weight quickly or perform at an elevated level usually receive high concentrate diets. This could include steers in a feedlot, dairy cows, or pigs on a finishing ration. Animals achieve a higher rate of performance based on the amount of energy they consume. Diets are balanced to supply enough energy to maintain the animal (net energy of maintenance, NE_m) and enough residual energy to allow the animal to perform to the level desired (net energy for gain, NE_g). Energy supplied by these types of diets usually comes from a grain source such as corn, barley, sorghum, wheat, oats or triticale.

Although this study does not include a corn-based diet, making some comparisons to corn seems applicable given corn is the most used grain source in feedlot diets (Owens et al., 1997). Corn is reported to have higher energy values than that of barley (2.24 vs 2.06 Mcal/kg NE_m, and 1.55 vs 1.4 Mcal/kg NE_g; NRC, 1996). These values for barley are conservative. Some authors (Zinn, 1993b; Boss and Bowman, 1996a; Ovenell-Roy et al, 1998a) report NE_m and NE_g values higher than those reported in the NRC. Owens et al. (1997) reviewed many feedlot studies and reported an average for metabolizable energy (ME) of barley at 17% greater than NRC value. This may be due partially to feeding ionphores in most diets in his review (Owens et al., 1997). Barley crude protein levels are higher than corn (avg 13.4 vs 10.1%; NRC, 1996). This increase in crude protein can help lower feed cost by reducing the need for added protein in the diet.

The principal grain used in feedlot diets has traditionally been corn. Anderson and Boyles (1989) reported that the most economical source of energy for feedlot diets

was dependent on the spread in price between corn and barley. During years when there is no difference in price between barley and corn, corn was the most economical energy source. However, if large price spreads were present, with barley being less expensive, then a combination of corn and barley diets were most economical.

There are several reasons why corn has been the preferred grain source in feedlot diets. In the mid-west where many large feedlots are located, corn is the least expensive and most available source of energy. Corn is also considered to be a safer energy source than barley. Incidence of bloat and acidosis are lower for corn-fed steers than for barley-fed steers. Grains with readily extracted starch, such as wheat or barley, are more likely to cause bloat or acidosis than corn or milo which have a slower rate of ruminal digestion (Owens et al., 1998). Ruminal barley starch digestion is usually >90%, (Waldo, 1973; Boss and Bowman, 1996b; Ovenell-Roy et al., 1998b). Corn starch digestion is more variable, with up to 40% of corn starch escaping rumen fermentation, however, cooked or steamed corn starch fermentation in the rumen is >90% (Waldo, 1973; Ørskov, 1986). These facts make one wonder if bloat and acidosis could be decreased by retarding fermentation of barley and other readily fermented grains in the rumen, or in other words make barley more like corn. In addition to reducing bloat and acidosis, Leng (1981) calculated that post-ruminal utilization of carbohydrates yields up to 30% more energy to the animal than when it is fermented in the rumen, and this may increase animal productivity (Trockmorton and Leng, 1984; Martin and Thomas, 1988). This may indicate that selecting potential new barley lines with reduced ruminal fermentation may be desireable.

Many researchers (Stock et al., 1990; Zinn et al., 1993a; Boss and Bowman, 1996a; Milner et al., 1996) have found that corn-based diets resulted in superior animal performance (ADG) compared to diets based on other grain sources. However, other research indicates steer performance (ADG) can be similar for steers fed barley diets versus corn diets (Nichols and Weber, 1988; Dion and Seone, 1992). Owens et al. (1997) reviewed numerous feedlot studies using corn, barley, oats, wheat and milo. There were no differences in ADG, DMI, or feed efficiency (feed/gain) when comparing barley and corn diets from different studies (1.42 kg/d vs 1.43 kg/d; 8.77 kg/d vs 8.93 kg/d; 6.24 kg feed/kg gain vs 6.32 kg feed/kg gain respectively; Owens et al., 1997). Zinn (1993b) reported steers fed barley diets outgained steers fed corn-based diets. Additionally, research in the Northwest indicates that even though steers fed corn gain more weight per day than steers fed barley, barley diets were more economical, and steers had improved feed conversion on barley diets (Boss and Bowman, 1996a; Milner et al., 1996). The decreased cost of barley versus corn in the Pacific Northwest is an important factor to be considered when formulating a backgrounding or finishing diet.

Starch Utilization in Ruminants

In feedlot diets, starch makes up the majority of the energy supplied to an animal. In barley, starch constitutes about 30-65% of grain weight and is concentrated in the endosperm (Bowman et al., 1997). There are two forms of starch, alpha-amylose and amylopectin. Alpha-amylose is composed of linear chains of D-glucopyranose units linked by alpha 1-4 linkages. Amylopectin contains chains of alpha (1, 4) D-glucopyranose units branched through alpha 1-6 linkages (Newman and Newman, 1992;

Garrett and Grisham, 1999). In British barleys, the majority of starch, (74-78%) is amylopectin, while the remainder (22-26%) is alpha-amylose. Waxy barleys contain only 0-3% amylose (Briggs, 1978).

Starch utilization is much different in ruminants and non-ruminants. Non-ruminants digest most starch within the intestinal lumen by alpha-amylase secreted by the pancreatic duct (Gray, 1992). Starch is rapidly degraded by hydrochloric acid in the stomach. Alpha-amylases bind to the terminal end glucose of the starch molecule and cleave it between the second and third alpha 1-4 linkages to produce maltose and maltotrioses. Maltases, then have the ability to cleave off glucose molecules. This is necessary because transport across the intestinal membrane is limited to glucose and other monosaccharides (Gray, 1992; Kellems and Church, 1998).

Starch degradation in ruminants is much different. The feedstuff undergoes a pregastric fermentation in which the ruminal microbes hydrolyze most of the available starch as an energy source (Merchen, 1988). Ruminants do not produce salivary amylase, so the first site of digestion is the rumen. The amount of starch that rumen microbes utilize depends on several factors including grain type, method of processing, diet and ruminant microbial species (Ørskov, 1986; Owens et al., 1986; Huntington, 1997). Grain types with hard covers such as corn and milo are less susceptible to ruminal microbes. Cracking or rolling grain exposes the endosperm to the ruminal microbes and allows the starch to be utilized more rapidly and to a higher degree. If this fermentation is too rapid, then digestive byproducts such as VFA's and lactic acid can overwhelm the animal's buffering capabilities and cause acidosis (Kotarski et al., 1992). The more surface area

exposed, the higher the digestion by the microbes (Kotarski et al., 1992). High grain diets cause a change in ruminal microbe species from cellulolytic such as *Bacteroides succinogenes, Ruminococcus flavefaciens*, and *Ruminococcus albus* to amylolytic species such as *Bacteroides amylophilus*, *Streptococcus bovis*, *Succinimonas amylolytica*, and *Bacteroides ruminicola* (Kotarski et al., 1992).

Following the rumen, digesta passes to the abomasum. However, most post-ruminal starch digestion takes place in the small intestine (Hill et al., 1991; Zinn, 1991). As in the rumen, the basis for starch digestion in the small intestine is enzymatic hydrolysis (Huntington, 1994). Intestinal amylase activity in the ruminant is very similar to that in the non-ruminant (Harmon, 1992). Some researchers have indicated that starch utilized in the small intestine is more efficiently utilized than starch hydrolyzed in the rumen and utilized by ruminal microbes. The theory behind this is that glucose is transported across the intestinal wall where it has approximately 40% higher energy than VFA's produced in the rumen when starch is fermented (Leng, 1981; Owens et al., 1986). There is some disagreement in the literature on this subject. Some research is being done with rapidly digested grains to hinder starch hydrolysis using formaldehyde and other treatments (Ortega-Cerrilla et al., 1999). However, Huntington (1997), in an extensive review, concluded that use of starch in the rumen was more beneficial than use in the small intestine. Huntington (1997) noted that approximately 45% of the starch entering the intestine was not absorbed as glucose. Therefore, any improvement in metabolic energetics attributable to increased glucose supply from dietary sources must consider potential losses of energy attributable to fermentation of starch in the cecum, large

intestine, and colon rather than in the rumen (Huntington, 1997). Huntington (1997) noted two benefits from ruminal digestion of starch: first, increased production and outflow of microbial protein from the rumen; and second, increased duodenal digestion of starch as a result of the pancreatic response to more protein entering the small intestine.

Starch can also be fermented in the large intestine, although not nearly to the extent of ruminal fermentation (Ørskov, 1986). This secondary fermentation produces the same products as ruminal fermentation, namely VFA's (Ørskov, 1986).

Total tract digestibility is usually >90% for high grain diets regardless of grain source (Owens et al., 1986; Spicer et al., 1986; Boss and Bowman, 1996b). Ruminal fermentation followed by enzymatic digestion in the small intestine and fermentation in the large intestine results in digestion of almost all of the available starch fraction of the diet, and therefore grain source has little effect on total tract digestibility. Site of starch digestion does differ based on grain source. Ørskov (1986), Owens et al. (1986) and Huntington (1997) reviewed starch utilization research and reported differences in site and extent of starch disappearance dependent upon the grain source. Figure 1 shows the differences in grain starch disappearance over time in the rumen. Corn and milo have the slowest rate of degradation, while oats, wheat, and barley have fairly rapid starch degradation. However, 48-h degradation is not different among the grains (Herrera-Saldana et al., 1990).

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; Gudmendsson and Eliasson, 1992). 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. Fannon et al. (1992) postulated that these pores may be the initial site of enzyme attack. Additionally, location of these pores may effect bacterial attachment and digestion, and may cause corn and sorghum to be less digestible in the rumen. Chemical composition of barley starch can differ dramatically, with some having rich amounts of amylose content and some having very low (waxy) amylose content. This difference may account for some of the variation found in digestibilities of different barley varieties.

Another possible effect on digestion of starch is the protein matrix. It is within this matrix that the starch molecules are embedded. McAllister (1991) evaluated the barley and corn starch matrix, and found that the corn protein matrix limited the access of rumen microbes to the starch granules. The protein matrix has a larger effect on corn digestion than barley digestion. When corn and barley were treated with proteases, digestion increased in both, with a larger increase in corn (McAllister et al., 1993).

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, Ørskov (1986) noted that the capacity for absorption of glucose may ultimately limit starch digestion in the small intestine. Huntington (1997) suggested that capacity to digest starch was the primary factor limiting absorption of glucose in the small intestine. Huntington (1997) simulated glucose transport by sodium-

glucose transporters in the intestine and found that transporters could transport nearly double the amount of glucose that was hydrolyzed in the small intestine of an animal receiving a high grain diet. He concluded that enzymatic starch digestion from pancreatic amylases was the limiting factor.

Barley Variety and Processing Effect on Animal Performance

Barley is a unique cereal grain in that so many cultivars exist in production (Gudmundsson and Eliasson, 1992). Barley has two main uses; the first is feed for livestock with approximately 70% of all barley being used as feed. The second use for barley is the malting industry. Some areas of the world use barley as a food source for human consumption, however, in the United States and Canada very little barley is used for human consumption (except indirectly through the malting industry). Barley breeding has revolved around these two uses, feed and malting. Any malting cultivar that does not meet the strict criteria of the malt industry is automatically designated feed barley regardless of its feed value.

Malting cultivars are either two-row or six-row, referring to the number of rows of kernels seen as a person looks down on the head. Malting barleys contain between 10-13% crude protein with preference given to a lower % of crude protein. Soluble protein of 5% minimum is required. Other requirements include kernel size with preference given to plumper kernels. Uniform, rapid germination of at least 96% is important. Barley should mature rapidly and break dormancy quickly. The presence and amount of the two enzymes alpha-amylase and beta-amylase are important factors in malting quality. Brewers usually prefer only moderate levels of beta-amylase, since excessive

levels may give rise to beers that are thin and lack "mouth feel" (Burger and LaBerge, 1985). One of the most important characteristics of a good malt barley is its consistency, or its ability to produce high quality and consistent malt between runs (Briggs, 1978).

Barley can be classified into several categories, waxy vs non-waxy, two-row vs six-row, and malt vs feed cultivars. Generally waxy types contain only amylopectin, hydrate faster and have increased rates of in vitro and in vivo digestion when compared with non-waxy cultivars (Huntington, 1994). However, Huntington (1994) stated that rates of digestion do not always correspond to animal performance. As stated earlier, this may indicate that selecting potential new barley lines with a slower rate of digestion may be desireable.

Barley feed quality has been examined with non-ruminants. Barley cultivars vary in beta-glucan levels, which have effected viscosity of digesta in chickens and caused impaired digestion (Wang et al., 1992). Differences in cultivars and variation in growing seasons make it difficult to estimate energy content of barley grain. Fairbairn et al. (1999) attempted to develop a system that could accurately estimate the DE and ME levels in individual barley samples for swine diets. They were able to estimate the energy content of barley grain using an equation, which included acid detergent fiber, acid detergent lignin, beta-glucan levels, and kernel density. However, they were only able to predict DE with 85% accuracy, confirming the large variation in the energy content of barley. Barley cultivar affects ADG, feed efficiency, and dry matter intake (DMI) when fed to pigs (Honeyfield et al., 1987).

Ruminant research has primarily focused on barley cultivar effect on animals fed feedlot diets. In the past, barley cultivars have been released with no consideration of feed quality. If a potential barley cultivar had desirable malting characteristics or showed potential for high yield, then it was released into production. A good example of this would be Steptoe barley. Steptoe has exceptional yield characteristics, however, in feedlot studies Steptoe-fed steers have not performed as well as steers fed other barley cultivars (Surber et al., 1998).

Recent emphasis has been placed on selecting barley cultivars based on digestibility. Clark et al. (1987) evaluated 16 cultivars of barley and reported that rate of in vitro dry matter digestibility (IVDMD) was effected by cultivar. They determined that IVDMD was a viable method of screening for barley cultivars with a slower rate of fermentation. Kemalyan et al. (1989) evaluated 8 barley lines using the in vitro technique and their results agreed with Clark et al. (1987) that barley cultivar did effect rate of IVDMD. They further postulated that selecting cultivars with slower rates of digestion may present additional starch to the small intestine for enzymatic digestion.

Rate, site, and extent of digestion appear to be similar among barley cultivars. Hatfield et al. (1993) reported that although starch content of several barley cultivars differed, rate, site and extent of digestion was not different for wethers fed diets based on Steptoe or Ottus barley. Boss and Bowman (1996b) reported that steers fed diets based on three different barley cultivars and one corn diet had similar ruminal starch digestion. However, steers fed barley diets had higher total tract starch digestion than steers fed

corn diets. Additionally in situ starch disappearance was faster for all three barley cultivars than for corn.

Bowman et al. (2000) reviewed 18 feedlot trials utilizing barley as the basal grain source throughout Idaho and Montana in an attempt to identify laboratory procedures that would predict animal performance. She determined that steers fed barley with slower rate of digestion had higher ADG than steers fed other barley lines. There appears to be a complex relationship between rate of digestion and ruminal digestion. Huntington (1997) suggests that starch is best utilized in the rumen. Bowman et al. (2000) suggests that slower rate of digestion is favorable. While these reports appear to contradict each other, there may be a relationship where a slower yet complete digestion in the rumen is the best situation.

Recent emphasis has been placed on determining the feed value of different barley cultivars in an effort to find complimentary breeds for developing improved feed quality cultivars. Feedlot studies throughout Montana, Idaho, Washington, and southern Canada, have attempted to document the feed value of different cultivars of barley.

Early work with different barley cultivars found that dry matter intake (DMI) for steers differed based on barley cultivar (Hinman, 1979), and that steers fed some cultivars tended to have better feed conversion. Preston and Herlugson (1980) fed steers high grain diets based on Boyer and Steptoe. They found that steers fed Boyer had a 12% advantage in rate of gain and feed efficiency over steers fed Steptoe. They also reported differences in carcass characteristics with steers fed Boyer having lower yield grades than steers fed Steptoe, however, no differences were found in USDA quality grades.

More recent work has examined many barley genotypes to determine steer performance, nutrient digestion, and carcass characteristics. Ovenell-Roy et al. (1998a) used 144 steers in an extensive feedlot trial to determine the effects of eight different barley cultivars; Andre, Camelot, Clark, Cougbar, Harrington, Steptoe, Boyer, and Hesk. Four of these cultivars are two-row, and four are six-row, additionally, four are malting cultivars, and four are considered feed cultivars. Differences in barley cultivars in their trial were extensive. Differences in starch digestibility were found with no clear trend in regard to malt or feed cultivar. Average daily gain differed with steers fed Cougbar, a malt cultivar having lower ADG than steers fed all other diets. Organic matter intake was also influenced by barley cultivar, again with no clear trend in regard to malt or feed cultivar. However, a trend was noticed in feed efficiency. Steers fed malting cultivars tended to have improved feed efficiency over most of the feed cultivars. Ovenell-Roy (1998a) also found differences in carcass characteristics for steers fed different barley diets. Differences were found in hot carcass weight, backfat thickness, ribeye area, and % kidney, pelvic, and heart fat. Differences are found not only across barley cultivars but also within barley cultivars. Ovenell-Roy et al. (1998a) also found that across two studies, Camelot barley had a CP content of 10.8% in study 1 and 15% in the second study.

The results found by Ovenell-Roy et al. (1998ab) exemplify what other researchers have found throughout the 1990's. Bradshaw et al.(1992) found ADF digestibility was greater for steers fed Steptoe than for those fed Klages barley.

Additionally, they reported that grain processing was necessary for steers to achieve maximum performance.

Boss and Bowman, (1996a) compared four diets, one based on corn and three based on either Harrington, Gunhilde, or Medallion barley. They found that steers fed Harrington barley, a malt cultivar, outgained steers fed Gunhilde or Medallion, both feed cultivars. However, steers fed corn out gained all steers fed barley diets. This may be related to digestible starch intake. Steers fed corn consumed more digestible starch than steers fed any barley diet, and steers fed Harrington consumed more digestible starch than steers fed Gunhilde or Medallion. This may indicate a relationship between ADG and digestible starch intake. They also reported differences in energy content of the grains. Medallion barley had higher NE_m than Harrington or Gunhilde barley and higher NE_g than Gunhilde barley. Final weights were heavier for steers fed Harrington, as well as hot carcass weights, higher marbling scores, USDA quality grades, and USDA yield grades. Also reported was an improvement in feed efficiency for steers fed Medallion over steers fed Gunhilde.

Other researchers report similar findings. Surber et al. (1998) fed four barley-based diets containing either Baronesse, Lewis, Steptoe, or Morex barley cultivars. Steers fed Morex, a malt cultivar, outgained steers fed Lewis or Steptoe while Baronesse-fed steers were not different from any treatment group. Differences were also reported in final steer weights and DMI.

Bowman et al. (1997), in an extensive review of the world barley core collection, reported starch content in barley grain ranged from 27-66%, acid detergent fiber ranged

from 0.79-13.8% and ISDMD ranged from 12-63%. She concluded that with so much variation in barley genotypes, the potential exists to exploit this variation and develop new barley lines designed specifically for feed quality.

Recent efforts have been made to improve the feed quality of barley for beef cattle. Blackhurst et al. (1999) and Boss et al. (1999) evaluated 8 experimental lines of barley which were developed with improved feed quality as part of the objectives in two feedlot studies in Montana. Blackhurst et al. (1999) reported that steers fed several of the experimental lines of barley had ADG similar to the parent lines and some numerically higher although not statistically different. Additionally, steers fed experimental barley line LB5 had higher marbling scores and USDA quality grades than steers fed the parent lines. Steers fed experimental barley line LB30 had a 12.5% increase in ADG over the mean of the parent lines, and had numerically higher gain/feed ratio (Boss et al., 1999). These studies show taking advantage of molecular genetics and plant breeding can make improvements in feed quality of barley.

Laboratory Procedures to Evaluate Feed Quality

One of the main goals of the Montana State University barley program is to determine what laboratory procedures will successfully predict feed quality of a barley cultivar using a relatively small amount of grain. Surber et al. (2000) reviewed 18 feedlot trials utilizing barley as the basal grain source throughout Idaho and Montana in an attempt to identify laboratory procedures that would predict animal performance. She found negative correlations between barley ISDMD and ADG ($r = -0.36$), barley ISDMD and barley NE_m and NE_g content ($r = -0.59$), and barley ISDMD and gain/feed ($r = -0.37$).

The negative relationship between ISDMD and ADG indicated that cattle fed barley with slower rate of digestion performed better in the feedlot.

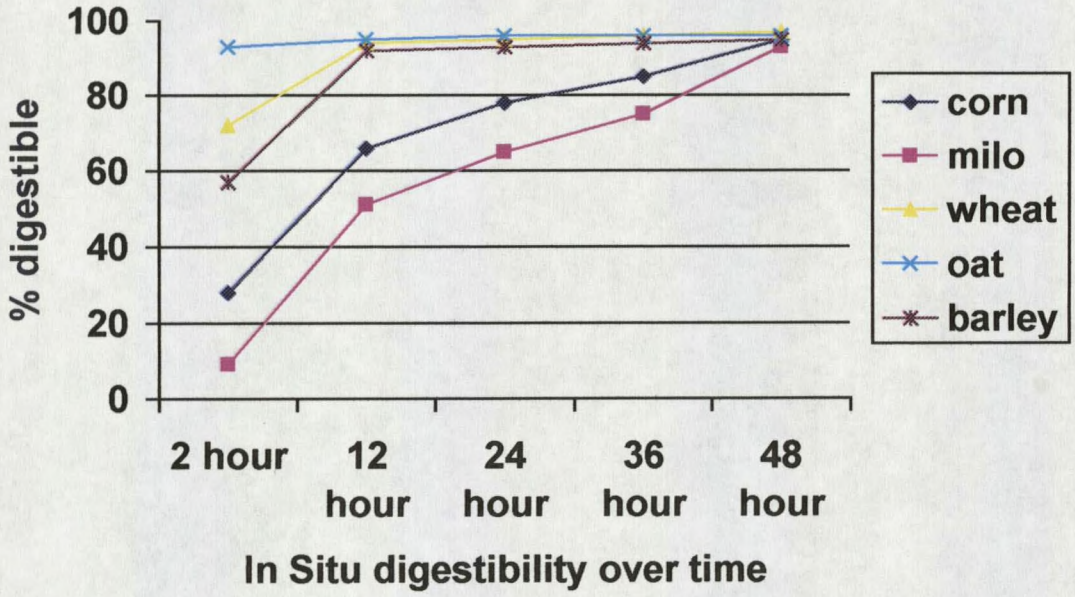
The parameter with the strongest correlation to ADG was starch intake (r = 0.53). Measuring starch intake requires animals to be in a feedlot situation, however, starch intake was negatively correlated to ADF content (r = -0.45). Selection for low ADF content in barley would therefore be desirable (Surber et al., 2000).

Barley starch content was positively correlated with barley NE_m and NE_g (r = 0.34; r = 0.37 respectively), positively correlated with gain/feed (r = 0.33) and negatively correlated with barley ADF content (r = -0.48). Selection for high starch content in barley would be desirable (Surber et al., 2000).

Particle size after dry rolling was negatively correlated to *in vivo* DMD (r = -0.68), negatively correlated to DMI (r = -0.31), and positively related to gain/feed (r = 0.35). Since in vivo DMD was also negatively correlated with ADG (r = -0.33), it appears that selection for large particle size in barley would be desirable (Surber et al., 2000).

The results from Surber et al. (2000) are encouraging as are the efforts of plant breeders and animal scientists to work together to improve the feed quality of barley for ruminants. Continued efforts at refining laboratory procedures to determine barley feed value should prevent future release of barley cultivars based solely on agronomic performance and benefit both grain producers and the livestock industry.

Figure 1. In situ starch disappearance of five cereal grains, corn, milo, wheat, oats, and barley. Adapted from Herrera-Saldana et al., (1990).



CHAPTER 3

1999 FEEDLOT STUDY

Materials and Methods

Eighty Angus x Hereford steers (avg initial weight 342 kg) were assigned to 16 pens based on equal pen weight in a randomized complete block design for a 159-d growth trial. The trial was divided into five 28-d data collection periods. Four diet treatments were based on two barley cultivars and two experimental lines of barley. Each treatment was fed to four pens. The treatment diets were: 1) Baronesse; 2) Lewis; 3) LB6; or 4) LB57. Baronesse is a European two-row feed cultivar noted for its high yield. Lewis is a two-row feed and malting barley developed in Montana. These two cultivars were crossed to develop lines of barley that could take advantage of Baronesse's high yield, and Lewis' malting characteristics and regional adaptability. Two experimental lines, LB6 and LB57 were selected from 64 recombinant inbred lines (RIL's) based on their yield and LB57's malting characteristics, and for their regional adaptation. In addition, both of these lines were fed in 1998 in a preliminary trial and performed similar to the parent lines in ADG and feed efficiency making them excellent candidates for further validation of feed quality.

All barley grains were grown under dryland conditions near Havre MT. Upon arrival at the Montana State University feed mill, grains were grab sampled and analyzed for dry matter (DM), crude protein (CP; AOAC, 1997), acid detergent fiber (ADF; Van Soest et al., 1991) and starch (Megazyme, Sidney, Australia), and test weights were taken.

Diets contained 83% cracked barley, 6% chopped straw (approximately 5 cm length) as a roughage source, and 3% soybean oil to bind ingredients, reduce dustiness and increase palatability (Table 1). All grain was coarsely cracked prior to feeding so that there were approximately 5% whole barley kernels. A supplement was also added at 8% of the diet that contained a TM premix, Vitamin A,D, and E premix, Rumensin premix, Tylosin premix and a small amount of oil. Supplements were mixed and bagged at the MSU feed mill. Colored microgrits were used in the supplements for positive identification and to avoid accidentally using the wrong supplement in a diet (Baronesse = blue; Lewis = orange; LB6 = green; LB57 = purple). Ground barley was used as a carrier in the supplement, and this brought the total amount of barley in the diets to approximately 85% (Table 1).

Grain samples from the four barley genotypes were cracked through a Buehler mill (to simulate dry rolling processing done prior to feeding barley). Mean particle size was determined on the cracked grain samples by a dry sieving technique (Fisher et al., 1988). Two ruminally cannulated beef cows consuming low-quality grass hay ad libitum and 3.6 $kg \cdot head^{-1} \cdot day^{-1}$ of barley were used to determine *in situ* DM digestibility (ISDMD) of the four barley genotypes. Duplicate nylon bags (10 cm x 20 cm, 50 μm pore size; Ankom Technology, Fairport, NY) for each of the genotypes containing a 5 g sample, along with duplicate blank bags, were placed into the rumen of both cows and removed after 3 h. After removal from the rumen, bags were washed with cold water until the rinse water was clear, squeezed to remove excess water, and dried at 60° C for 48 h in a forced-air oven. After drying, bags and residue were weighed and ISDMD was

calculated using the following equation: ISDMD, % = [100-[(((dry bag + sample weight out) - bag weight) – blank) / dry sample weight in]] * 100.

Diets were balanced to be isocaloric (2.02 Mcal/kg NE_m, 1.36 Mcal/kg Ne_g) and isonitrogenous (13% CP). Urea was used in the supplement to balance for crude protein. Diet samples were taken from the feed mixer prior to the morning feeding every 14-d and composited by treatment and period. These samples were analyzed for DM, organic matter (OM), CP (AOAC, 1997), starch (Megazyme, Sidney, Australia), ADF (Van Soest et al., 1991), and acid insoluble ash (AIA; Van Kuelen and Young, 1977). Prior to analysis, diet samples were ground in a Wiley mill to pass a 1-mm screen.

Steers were given a 28-d adaptation period to adjust to their respective diets. During this period barley levels in the diets were slowly increased from 79% to 83%. Each of the four diets were mixed daily in a large feed wagon. Diets were allowed to mix for 10 minutes each morning to assure ingredients were completely mixed. Order of feeding was rotated daily so that each pen was fed first every four days. Steers were implanted with Ralgro® (Schering-Plough Animal Health Corp., Kenilworth, NJ) on day 1 of the trial, and with Synovex-Plus® (Fort Dodge Animal Health, Overland Park, KS) on d 56. Water was offered ad libitum throughout the experiment. Steers were given ad libitum access to feed, which was offered once daily between 0700 and 0900. Feed bunks were inspected daily before feeding to allow for adjustments to be made in feed offered. Feed offered was recorded daily and bunks were swept every 28-d and refusals weighed and recorded. Strict guidelines were set to govern when feed amount could be increased. Amount of feed offered was not to be increased two days in a row. Feed

bunks were to be slick two days in a row before feed amount was increased. In addition, feed was not to be increased over a weekend when no one was assigned for afternoon checks. Pens were cleaned and bedded with fresh straw weekly. Time of cleaning was recorded. Steers were weighed every 28-d and ADG and feed efficiency (kg gain/kg feed) were calculated. Initial and final weights were obtained by weighing the steers on two consecutive days and taking the average weight

Fecal grab samples were taken every 28-d from each steer and composited by pen. Fecal samples were analyzed for DM, OM, CP (AOAC, 1997), starch (Megazyme, Sidney, Australia), ADF (Van Soest et al., 1991), and AIA (Van Kuelen and Young, 1977). Prior to analysis, fecal samples were dried in a forced-air oven at 60° C for 24 h and ground in a Wiley mill to pass a 1-mm screen. Acid insoluble ash was used as an internal marker to estimate average pen fecal output with the following equation: Fecal output = (AIA intake, g/d)/(concentration of AIA in feces, g/g DM). Fecal output was then used with intake to determine diet digestibility by the following equation: Digestibility = [(Intake – Fecal output)/Intake] * 100.

All steers were observed for signs of sickness at 1100 and 1500 daily. Any steers showing signs of bloat were treated immediately. Respiratory disease, footrot or other viral/bacterial infections were treated according to the attending veterinarian's recommendation. Records were kept of any animals treated, which included animal number, date, and treatment procedure.

Steers were slaughtered when 70% were visually estimated to grade choice. They were processed at E. A. Miller's slaughter plant in Hyrum, Utah. Hot carcass weights

and liver scores were taken on the day of slaughter, all other carcass measurements were taken after a 24-h chill. Kidney, heart and pelvic fat (KPH), marbling, backfat thickness, and preliminary yield grade were assigned by Miller's grading manager, while quality grade, and yield grade were assigned by a USDA grader. The ribeye muscle was traced on transparencies and a planimeter was used to determine ribeye area.

Average body weight, DMI, ADG, and steer NE_m and NE_g requirements for each pen were used to estimate diet NE_m and NE_g (Zinn, 1993). Diet NE_m and NE_g were estimated using an iterative process (NRC, 1996) to fit the relationship $NE_g = (0.877\ NE_m) - 0.41$. Steer requirements for NE_m and NE_g were estimated using the following equations: NE_m, Mcal/d = $0.077\ BW^{0.75}$ (Lofgreen and Garrett, 1968) and NE_g, Mcal/d = $(0.0557\ BW^{0.75})\ ADG^{1.097}$ (NRC, 1996). Barley NE_m and NE_g were estimated using the following equations: Total diet NE_m, Mcal/kg = (0.83 x NE_m barley) + (0.06 x NE_m straw) + (0.029 x NE_m oil) + (0.081 x NE_m supplement) and total diet NE_g, Mcal/kg = (0.83 x NE_g, barley) + (0.06 x NE_g straw) + (0.029 x NE_g oil) + (0.081 x NE_g supplement), where the constants 0.83, 0.06, 0.029, and 0.081 represent the portion of barley, straw, oil, and supplement in the diet. Values of 0.617 Mcal/kg NE_m and 0.099 Mcal/kg NE_g were used for the straw. Values of 5.886 Mcal/kg NE_m and 4.412 Mcal/kg NE_g were used for the oil. Values for NE_m and NE_g of the supplement were based on the supplement formulation and were: 0.582 Mcal/kg NE_m and 0.066 Mcal/kg NE_g.

Data were analyzed as a randomized complete block design using the GLM procedure of SAS, with pen as the experimental unit (SAS Inst., Cary, NC). Previous research has shown cattle performance differences based on side of the feedlot, therefore

side of the feedlot was block. Figure 2 shows the configuration of the pens and which pen received which treatment. Performance data were analyzed for block, period, and treatment effects and the interactions were tested (Appendix Table 1). We also tested a contrast statement to see if there were differences between the experimental lines and the mean of the parent varieties. Digestibility data were tested for block, treatment, and period effects using repeated measures, and all interactions were tested. We also used contrast statements with digestibility data to test for differences between experimental lines and mean of the parents. Carcass data were tested for block and treatment effects and the interaction was tested. Contrast statements were used to test for differences between experimental lines and parent lines. Least squares means were separated by the LSD procedure of SAS if a significant F-test was found ($P < 0.10$). Least squares means and the associated standard errors are reported.

Results and Discussion

Grain and Diet Analysis

Laboratory analysis of Lewis, Baronesse, LB6 and LB57 barley grains indicated a crude protein range of 11.57-13.52%. Starch ranged from 56 to 61%. In situ dry matter digestibility (ISDMD) ranged from 37 to 42%. Calculations determining net energy revealed that all grains were substantially higher in energy than NRC values for barley grain (Table 2).

Chemical analysis of diet samples indicated a CP range of 11.3-13%. This was unexpected as diets were balanced for 13% CP (Table 3). It was determined that there was a mixing error in the supplement, as all samples taken were consistent in CP content. Diet samples were tested by treatment and period throughout the study, and results indicate diets were consistent in CP, starch, ADF, DM, and OM content throughout the study (Table 4). Starch content was similar for all diets with a range of 47.7-48.5% (Table 3).

Performance Data

No differences were found in initial ($P = 0.16$) or final ($P = 0.77$) weights for any treatment group, however, steers fed LB57 were slightly lighter ($P = 0.05$) in initial weights than steers fed parent lines (340 kg vs 342.5 kg avg). No differences were found in ADG for treatment ($P = 0.62$), with a mean ADG of 1.50 kg/d (Table 5). These results are consistent with Blackhurst et al. (1999), who, in a preliminary study, reported no differences in ADG for steers fed these same barley lines. These results also agree with Surber et al. (1998) who found no differences in ADG for steers fed Baronesse and Lewis

barley-based diets. However other researchers have found differences in ADG for steers fed different barley cultivars. Boss et al. (1999) reported differences in ADG with steers fed LB13 and LB30 gaining more weight per day than steers fed Baronesse. Additionally, Ovenell-Roy et al. (1998) found that steers fed Cougbar barley had lower ADG than steers fed Andre, Camelot, Clark, Harrington, and Steptoe barley cultivars.

There was no treatment x period interaction for ADG ($P = 0.60$; Table 7). Steers fed LB6 or LB57 had similar ($P = 0.62$) ADG to those fed Baronesse or Lewis. There were no differences in ADG between LB6 and the mean of the parents ($P = 0.89$), or between LB57 and the mean of the parent lines ($P = 0.71$; Table 5).

An economically important finding in this study concerns feed efficiency. Although there were no differences in ADG, and no treatment differences ($P = 0.20$) in feed efficiency, steers on LB6 gained more weight per unit of feed ($P = 0.06$) than steers fed parent lines (Table 5). Blackhurst et al. (1999) reported LB6 and LB57 had similar feed efficiency to the parent lines. These results show that LB6 and LB57 have performed as well as or better than the parent lines for two consecutive years, indicating that feed efficiency was not sacrificed when these lines were developed. Our results also agree with Surber et al. (1998) who reported that Baronesse-fed steers had similar feed conversion as steers fed Lewis.

We estimated that feed costs were approximately \$0.12/kg. When that was multiplied by daily intake, it cost approximately \$1.08/day to feed the steers fed Baronesse, LB57 and Lewis, while it only cost approximately \$1.03/day to feed the steers fed LB6. This was nearly a 5% savings in feed cost. This was especially important

noting that there were no treatment differences in ADG or carcass characteristics. Over our 159-d trial, this accounted for $8.00 less per head in feed costs for steers fed LB6 diets. In a 10,000-head feedlot, that would be an $80,000 savings per group of steers.

Nutrient Intake

Steers fed the LB6 diets consumed 4.5% less ($P = 0.01$) DM per day than steers fed Baronesse, Lewis, or LB57 (8.5 kg/d vs. 8.9 kg/d avg; Table 6). These results differ from those found by Blackhurst et al. (1999), who reported that steers fed LB6 diets consumed more DM than steers fed Lewis diets. Steers fed LB6 consumed less ($P = 0.004$) DM than steers fed parent lines. However, steers fed LB57 consumed the same ($P = 0.65$) amount of DM as steers fed parent lines. This agrees with Blackhurst et al. (1999) who found that steers fed LB57 consumed the same amount of DM as steers fed Baronesse and Lewis diets.

Steers fed LB6 consumed less ($P = 0.02$) starch than steers fed Baronesse, Lewis, or LB57 (4.13 vs 4.30 kg/d avg; Table 6). Additionally, steers fed LB6 consumed less ($P = 0.009$) starch than the mean of the parent lines (4.13 vs 4.3 kg/d avg). Steers fed LB57 consumed the same amount of starch as steers fed parent lines (4.3 kg/d avg).

Acid detergent fiber intake was highly variable. Steers fed LB57 consumed more ($P = 0.0001$) ADF than steers fed LB6 (0.85 kg/d vs 0.69 kg/d) while steers fed Lewis or Baronesse were intermediate in ADF intake (0.72 kg/d and 0.73 kg/d, respectively) and differed from both LB6 and LB57 (P = 0.001; Table 6). Acid detergent fiber intake was lower ($P = 0.01$) for steers fed LB6 than for steers consuming parent lines. Acid detergent fiber intake was greater ($P = 0.0001$) for LB57-fed steers than for

steers fed parent lines. Nitrogen intake was highest for steers fed Baronesse, with steers fed LB57 consuming the least nitrogen, and Lewis and LB6 intermediate in nitrogen intake (Table 6).

Digestibility

In vivo digestibilities were calculated for each 28-d period. Diets based on LB6 and Lewis had 3% higher ($P = 0.002$) DMD than did Baronesse or LB57 diets (avg 74.5 vs avg 72.3%, respectively; Table 6). It is likely this increase in DMD was a factor in LB6 fed steers having improved feed efficiency over steers consuming parent lines. Diets based on LB6 were also higher ($P = 0.03$) in digestibility than the mean of the parent lines (74.7 vs avg 73.2%), but no differences were found in DMD between LB57 diets and the parent lines. Blackhurst et al. (1999) reported no differences in *in vivo* digestibility for these same diets.

Starch digestibility did not differ among diets ($P = 0.37$) with a mean of 96.5% (Table 6). These results differ from those found by Surber et al. (1998) who reported that Baronesse diets had higher starch digestibility than Lewis diets. Ovenell-Roy et al. (1998) also found differences in starch digestibility for diets based on six different barley cultivars.

There was a wide range in ADF digestibility, with LB57 having higher ($P = 0.001$) ADF digestibility than Baronesse or Lewis (13.9% vs –1.1 and 5.8%, respectively) with LB6 being intermediate in ADF digestibility and not different from LB57 or Lewis, but higher ($P = 0.001$) than Baronesse (10.4%; Table 6). This variation could be due to differences in digestibility of the ADF in the grain or it may be due to a drop in rumen pH

inhibiting fiber digestion of the forage or it might be due to rate of passage. These results may warrant further research.

Digestible dry matter intake followed DMD with steers fed Lewis consuming more ($P = 0.01$) digestible DM than steers fed other diets, and steers fed LB6 consuming less ($P = 0.05$) than steers fed parent lines (Table 6). Digestible starch intake was similar to DMI with steers fed LB6 consuming less starch ($P = 0.02$) than steers fed other diets. Steers fed LB57 consumed more ($P = 0.001$) digestible ADF than steers fed all other diets with steers fed Lewis or LB6 consuming more than steers fed Baronesse.

Diet digestible starch content was highest ($P = 0.001$) for LB57 and LB6 diets, lowest for Baronesse, and intermediate for Lewis diets (Table 6). Diet digestible ADF content was highest ($P = 0.001$) for LB57 diets, lowest for Baronesse diets, and intermediate for Lewis and LB6 diets.

Steers fed LB57 had higher ($P = 0.008$) fecal output than steers fed LB6 while steers fed Baronesse had higher fecal output than steers fed LB6 or Lewis, but not different than steers fed LB57 (Table 6). No treatment differences ($P = 0.61$) were found for starch fecal output and there were no differences between the experimental lines or the mean of the parent lines.

Some period effects were noticed in nutrient intake. Dry matter intake increased ($P = 0.001$) with each period throughout the study. However, starch intake and ADF intake increased the first four periods and then decreased ($P = 0.002$) during the last period (Table 7). Additionally, DMD was consistent throughout the study except during period 4 when DMD dropped ($P = 0.002$) approximately 4% from the other four periods.

In addition to the lowest DMD, period four also had the highest ($P = 0.002$) ADF digestibility.

Carcass Characteristics

We found no differences ($P > 0.24$) in carcass characteristics due to treatment. Hot carcass weights averaged 334 kg, marbling scores averaged 4.6 (3 = slight, 4 = small, 5 = modest), quality grades averaged 12.3 (11 = select, 12 = choice-), % kidney, pelvic and heart fat averaged 2.25%, backfat averaged 1.05 cm, longissimus dorsi area averaged 77.6 cm^2, and yield grade averaged 2.9 (Table 8). When LB6-fed steers were compared to steers fed the parent lines for carcass characteristics, LB6-fed steers were slightly lower in marbling and quality grade ($P = 0.06$ and 0.07, respectively) than steers fed the parent lines. No differences were found between steers fed LB57 and steers fed the parent lines. These results are consistent with those reported by Blackhurst et al. (1999) who found no differences in carcass characteristics between Baronesse, Lewis, LB6, and LB57. However, Blackhurst et al. (1999) did report differences in carcass characteristics, including marbling score and quality grades, between Baronesse, Lewis and several other RIL's from a Baronesse x Lewis cross. Researchers have reported varying results in carcass characteristics of steers fed different barley cultivars. Surber et al., (1998) reported no differences for any of the same variables we measured for steers fed Baronesse, Lewis, Steptoe or Morex barley cultivars. However, Ovenell-Roy et al. (1998) reported differences in hot carcass weight, backfat thickness, longissimus dorsi area, and % kidney, pelvic and heart fat, for steers fed six different barley cultivars.

Correlations

One main goal of the Montana State University barley project is to find ways of evaluating barley in a laboratory that will successfully predict animal performance. Therefore, we ran correlations on several variables we measured to determine if any of the lab procedures would predict animal performance. Although none of the variables we tested successfully predicted ADG ($P > 0.20$; Table 9), we had a limited number of observations. Surber et al. (2000) reported that barley ISDMD was highly correlated with ADG and feed efficiency when using results from 18 feedlot studies including this one.

We also made correlations between animal performance and intake and *in vivo* digestibility (Table 10). We found that DMI was highly correlated with ADG and feed efficiency ($P = 0.004$ and 0.001, respectively). Acid detergent fiber was highly correlated ($P = 0.0001$) with feed efficiency. Starch intake was also highly correlated with ADG and feed efficiency ($P = 0.05$ and 0.0001, respectively).

CHAPTER 4

CONCLUSIONS AND IMPLICATIONS

Experimental barley line LB6 had improved feed efficiency compared to parent lines. Experimental barley lines LB6 and LB57 were fed in 1998 in a pilot trial and again in 1999 in this study. For two consecutive years these barley lines, which were selected for improved agronomic performance and malting quality, have had improved or similar feed efficiency as the parent lines. This is also the second year these improved lines have had ADG that is as good as the parent lines, demonstrating no reduction in feed quality. This is especially important noting that there were no losses in carcass quality.

This research project is helping identify and understand the factors that effect feed quality in barley. In the future this should allow the development of standard feed quality criteria similar to malt quality criteria that currently exist. This could provide the potential for feed quality certification of barley and enhanced value. This project may set a precedence for future release of new barley cultivars, by showing that testing feed quality before release is of value to both grain and livestock producers. Hopefully in the near future we can accomplish this with laboratory procedures and eliminate costly feedlot trials.

The practical importance of feed efficiency cannot be overlooked in this research. Steers fed diets based on LB6 cost $8.00 less per head to feed over the duration of the trial than steers fed all other diets. With margins for profit so small in today's cattle market, these savings may mean profit or loss for producers or feedlot owners.

Figure 2

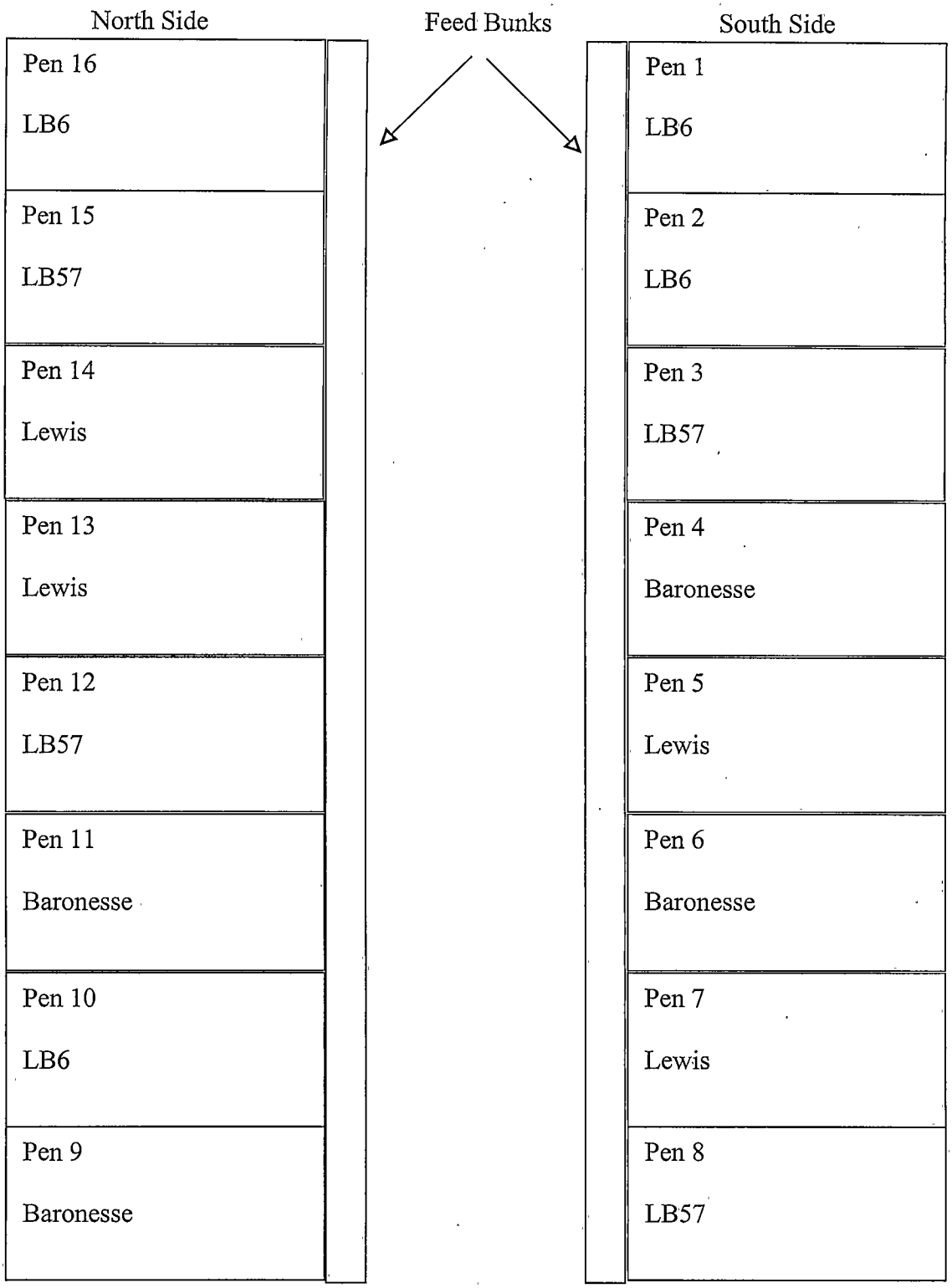

North Side
Feed Bunks
South Side
Pen 16
LB6
Pen 15
LB57
Pen 14
Lewis
Pen 13
Lewis
Pen 12
LB57
Pen 11
Baronesse
Pen 10
LB6
Pen 9
Baronesse
Pen 1
LB6
Pen 2
LB6
Pen 3
LB57
Pen 4
Baronesse
Pen 5
Lewis
Pen 6
Baronesse
Pen 7
Lewis
Pen 8
LB57

Table 1. Composition of diets containing Baronesse, Lewis, LB6, or LB57 barley as the basal grain

Item	BAR	LEW	LB6	LB57
Ingredient		% DM Basis		
Cracked barley	83.0	83.0	83.0	83.0
Straw, chopped	6.0	6.0	6.0	6.0
Soybean oil	2.9	2.9	2.9	2.9
Supplement				
Ground barley	2.15	2.15	2.15	2.15
Oil	0.09	0.09	0.09	0.09
Urea	0.91	0.45	0.85	1.02
Calcium carbonate	2.05	2.52	2.11	1.95
Sodium bicarbonate	1.28	1.28	1.28	1.28
Potassium chloride	0.78	0.78	0.78	0.78
Sodium chloride	0.49	0.49	0.49	0.49
TM premix	0.25	0.25	0.25	0.25
Vitamin ADE premix	0.05	0.05	0.05	0.05
Rumensin	0.0235	0.0235	0.0235	0.0235
Tylan	0.0130	0.0130	0.0130	0.0130
Microgrits	0.0122	0.0122	0.0122	0.0122

[a] TM premix contained 20.0% Mg, 6.0% Mn, 5.0% Fe, 2.7% S, 1.5% Cu, .11% I, .01% Se, and .01% Co.

[b] Vitamin A, D, E premix contained 30,000 IU/g vitamin A, 6,000 IU/g vitamin D, and 7.5 IU/g vitamin E.

[c] Rumensin premix contained 132 g/kg of monensin, Tylan premix contained 88 g/kg of tylosin.

Table 2. Chemical analysis for barley grains Baronesse, Lewis, LB6 and LB57

Item	BAR	LEW	LB6	LB57
DM, %	91	88	90	89
CP, %DM	11.89	13.52	12.09	11.57
ADF, %DM	6.73	5.15	4.28	5.12
Starch, %DM	56.21	60.02	61.30	60.03
Particle size, μm	1199.3	1179.4	1392.1	1310.1
ISDMD, %	39.50	38.68	37.28	41.82
NE_m, Mcal/kg [a]	2.37	2.41	2.49	2.37
NE_g, Mcal/kg [a]	1.68	1.72	1.79	1.68

[a] Calculated from actual performance and intake data.

Table 3. Chemical composition of diets based on Baronesse, Lewis, LB6 or LB57 barley

Nutrient	BAR	LEW	LB6	LB57
Crude protein, %DM	13.0	11.9	12.2	11.3
Acid insoluble ash, %DM	1.01	0.99	1.02	1.01
Acid detergent fiber, %DM	8.2	8.0	8.1	9.4
Starch, %DM	47.7	47.7	48.5	48.3
NE_m, Mcal/kg [a]	2.22	2.26	2.32	2.22
NE_g, Mcal/kg [a]	1.54	1.57	1.62	1.54

[a] Calculated from actual performance and intake data.

Table 4. Chemical analysis of diet samples by period for diets containing Baronesse, Lewis, LB6, and LB57 barley grain (% DM basis)

Item	BAR	LEW	LB6	LB57
Dry matter				
Period 1	93.5	93.7	93.3	93.4
Period 2	91.9	91.8	92.0	92.4
Period 3	91.2	91.2	91.7	91.7
Period 4	92.0	91.9	92.3	92.5
Period 5	91.9	92.4	92.3	92.6
Organic matter				
Period 1	93.1	91.6	92.5	92.8
Period 2	92.3	91.9	92.4	89.6
Period 3	92.9	93.4	93.5	91.9
Period 4	93.3	92.9	92.9	92.5
Period 5	92.8	93.0	93.0	92.8
Acid detergent fiber				
Period 1	7.8	6.9	6.9	7.8
Period 2	7.7	7.4	7.1	8.4
Period 3	8.3	7.3	7.5	9.5
Period 4	10.0	9.7	10.5	10.6
Period 5	7.5	8.5	8.4	10.7
Crude protein				
Period 1	12.7	12.2	12.1	11.0
Period 2	12.9	11.6	12.1	11.7
Period 3	13.5	12.0	12.5	11.4
Period 4	13.1	11.8	12.2	11.4
Period 5	12.9	11.8	12.1	11.0
Acid insoluble ash				
Period 1	1.0760	0.9981	0.8777	0.8953
Period 2	1.1446	1.0544	1.1136	0.8740
Period 3	0.8518	0.8423	0.9432	1.1801
Period 4	0.9902	1.0505	1.1230	1.0447
Period 5	0.9938	0.9909	1.0448	1.0523
Starch				
Period 1	40.1	41.7	47.2	44.9
Period 2	49.6	49.0	47.1	47.6
Period 3	47.6	47.2	48.9	43.8
Period 4	54.0	54.4	55.4	49.8
Period 5	47.3	47.6	43.6	48.2

Table 5. Feedlot performance of steers fed diets based on Baronesse, Lewis, LB6, or LB57 barley

	Barley Variety					Contrast statement		
Item	BAR	LEW	LB6	LB57	SE	*P*-Value	LB6 v Parents	LB57 v Parents
Pens, no.	4	4	4	4				
Initial wt, kg	342	343	342	340	0.84	0.16	0.93	0.05
Final wt, kg	574	588	576	581	9.8	0.77	0.72	0.99
ADG, kg/d	1.46	1.54	1.48	1.51	0.04	0.62	0.89	0.71
FE, kg gain/100 kg feed	16.9	17.4	18.0	17.3	0.3	0.20	0.06	0.82

Table 6. Intake, fecal output, *in vivo* digestibility, digestible intake, and diet digestible nutrient content of barley diets Baronesse, Lewis, LB6 and LB57

Item	BAR	LEW	LB6	LB57	SE	*P* value	LB6 vs Parents	LB57 vs Parents
No. of pens	4	4	4	4	----	----	----	----
Intake, kg/d								
DM	8.8^{b}	9.0^{b}	8.5^{a}	9.0^{b}	0.10	0.01	0.004	0.65
OM	8.2^{b}	8.3^{b}	7.9^{a}	8.2^{b}	0.10	0.03	0.006	0.88
Starch	4.26^{b}	4.33^{b}	4.13^{a}	4.31^{b}	0.05	0.02	0.009	0.75
ADF	0.73^{b}	0.72^{b}	0.69^{a}	0.85^{c}	0.009	0.001	0.01	0.001
Nitrogen	0.184^{c}	0.170^{b}	0.166^{ab}	0.161^{a}	0.002	0.001	0.001	0.001
Fecal output, kg/d								
DM	2.45^{bc}	2.31^{ab}	2.18^{a}	2.48^{c}	0.07	0.008	0.02	0.21
OM	2.13^{b}	1.97^{a}	1.87^{a}	2.15^{b}	0.06	0.007	0.02	0.21
Starch	0.17	0.15	0.14	0.15	0.01	0.61	0.33	0.46
ADF	0.73^{c}	0.72^{bc}	0.62^{a}	0.68^{b}	0.02	0.003	0.004	0.39
Nitrogen	0.049^{b}	0.044^{a}	0.044^{a}	0.049^{b}	0.002	0.03	0.13	0.22
Diet digestibility, %								
DM	72.1^{a}	74.3^{b}	74.7^{b}	72.5^{a}	0.55	0.002	0.03	0.27
OM	73.8^{a}	76.4^{b}	76.5^{b}	74.0^{a}	0.59	0.009	0.16	0.04
Starch	96.1	96.5	96.7	96.7	0.28	0.37	0.23	0.30
ADF	-1.1^{a}	5.8^{b}	10.4^{bc}	13.9^{c}	2.61	0.001	0.01	0.006
Nitrogen	73.1^{b}	73.9^{b}	73.9^{b}	69.8^{a}	0.79	0.001	0.003	0.70
Digestible intake, kg/d								
DM	6.4^{a}	6.7^{b}	6.3^{a}	6.5^{a}	0.07	0.01	0.05	0.59
OM	6.1^{a}	6.3^{b}	6.0^{a}	6.1^{a}	0.07	0.01	0.06	0.18
Starch	4.1^{ab}	4.2^{b}	4.0^{a}	4.2^{b}	0.05	0.02	0.01	0.56
ADF	0.003^{a}	0.05^{b}	0.08^{b}	0.13^{c}	0.018	0.001	0.02	0.001
Nitrogen	0.135^{c}	0.126^{b}	0.123^{b}	0.113^{a}	0.002	0.001	0.003	0.001
Diet digestible nutrient content, %								
Starch	45.8^{a}	46.3^{b}	46.8^{c}	46.7^{c}	0.14	0.001	0.001	0.005
ADF	-0.03^{a}	0.51^{b}	0.91^{bc}	1.36^{c}	0.210	0.002	0.01	0.001

[a, b, c] Within a row, means without a common superscript letter differ ($P < 0.10$).

Table 7. Animal performance, fecal output, diet digestibility, digestible intakes, and diet digestible nutrients of steers fed Baronesse, Lewis, LB6, or LB57 barley diets by period

Variable	Period					*P* Values		
	1	2	3	4	5	Period	P * T[1]	B * T[2]
ADG	1.26[a]	1.55[c]	1.96[d]	1.41[b]	1.41[b]	0.001	0.60	0.008
FE, g/f	0.18[b]	0.19[b]	0.22[c]	0.14[a]	0.14[a]	0.001	0.28	0.09
Intake, kg/d								
DM	7.0[a]	8.2[b]	9.0[c]	9.8[d]	10.1[e]	0.001	0.41	0.002
OM	6.5[a]	7.5[b]	8.4[c]	9.1[d]	9.3[e]	0.001	0.32	0.002
Starch	3.2[a]	4.0[b]	4.2[c]	5.2[e]	4.7[d]	0.001	0.001	0.001
ADF	0.5[a]	0.6[b]	0.7[c]	1.0[e]	0.9[d]	0.001	0.001	0.004
Nitrogen	0.133[a]	0.159[b]	0.178[c]	0.189[d]	0.192[d]	0.001	0.01	0.001
Fecal output, kg/d								
DM	1.8[a]	2.2[b]	2.3[b]	2.8[d]	2.6[c]	0.001	0.03	0.001
OM	1.5[a]	1.9[b]	2.0[bc]	2.5[d]	2.2[c]	0.001	0.04	0.001
Starch	0.09[a]	0.13[b]	0.15[bc]	0.23[d]	0.17[c]	0.001	0.08	0.007
ADF	0.49[a]	0.66[b]	0.66[b]	0.85[d]	0.79[c]	0.001	0.01	0.007
Nitrogen	0.037[a]	0.044[b]	0.048[b]	0.056[c]	0.048[b]	0.001	0.22	0.005
Diet digestibility, %								
DM	73.9[b]	73.4[b]	74.2[b]	70.8[a]	74.7[b]	0.003	0.001	0.004
OM	75.9[bc]	74.9[b]	75.8[bc]	72.6[a]	76.7[c]	0.007	0.002	0.006
Starch	97.2[c]	96.7[bc]	96.5[b]	95.6[a]	96.5[b]	0.02	0.09	0.008
ADF	4.5[b]	-4.5[a]	11.0[bc]	14.8[c]	10.5[bc]	0.002	0.004	0.18
Nitrogen	72.1[ab]	72.2[ab]	73.2[b]	70.5[a]	75.4[c]	0.006	0.006	0.004
Digestible intake, kg/d								
DM	5.2[a]	6.0[b]	6.7[c]	6.9[d]	7.5[e]	0.001	0.001	0.24
OM	4.9[a]	5.6[b]	6.4[c]	6.6[d]	7.2[e]	0.001	0.001	0.35
Starch	3.1[a]	3.9[b]	4.1[c]	5.0e	4.5[d]	0.001	0.001	0.009
ADF	0.02[b]	-0.02[a]	0.08[c]	0.15[d]	0.10[c]	0.001	0.002	0.06
Nitrogen	0.096[a]	0.115[b]	0.131[c]	0.134[c]	0.145[d]	0.001	0.001	0.59
Diet digestible nutrient content, %								
Starch	44.1[a]	46.8[c]	45.2[b]	51.1[d]	45.0[b]	0.001	0.001	0.008
ADF	0.31[b]	-0.30[a]	0.88[c]	1.53[d]	1.02[cd]	0.001	0.003	0.07

[1] Period x Treatment interaction

[2] Block x Treatment interaction

Table 8. Carcass characteristics of steers fed barley diets based on Baronesse, Lewis, LB6, or LB57 barley

Item	BAR	LB57	LB6	LEW	*P* value	SE	LB57 vs Parents	LB6 vs Parents
Carcass wt, kg	332.3	336.3	333.4	334.9	0.96	5.87	0.71	0.98
Marbling[a]	4.8	4.7	4.4	4.7	0.24	0.15	0.71	0.06
Quality grade[b]	12.4	12.3	11.9	12.3	0.30	0.16	0.72	0.07
KPH, %	2.3	2.2	2.2	2.3	0.61	0.09	0.50	0.24
Backfat, cm	1.02	1.18	1.02	0.97	0.43	0.06	0.13	0.74
LDA[c], cm^2	76.1	77.5	77.4	79.5	0.44	1.43	0.90	0.83
Yield Grade	3.0	3.0	2.9	2.8	0.39	0.06	0.27	0.90

[a] 3 = slight, 4 = small, 5 = modest
[b] 11 = select, 12 = choice-
[c] Longissimus dorsi area

Table 9. Correlations between animal performance, and laboratory analyses of Baronesse, Lewis, LB6 or LB57

Item	ADG	Gain/Feed	DMI
Barley ISDMD			
r =	0.053	-0.178	0.724
P =	0.946	0.508	0.275
Barley ADF			
r =	-0.714	-0.365	0.421
P =	0.285	0.164	0.578
Barley starch			
r =	0.794	0.345	-0.303
P =	0.205	0.190	0.696
Barley particle size			
r =	0.089	0.294	0.722
P =	0.910	0.267	0.277

Table 10. Correlations between animal performance and nutrient intake or *in vivo* digestibility of feedlot diets based on Baronesse, Lewis, LB6 or LB57

Item	ADG	Gain/Feed
DMI		
r =	0.32	-0.38
P =	0.003	0.004
Starch intake		
r =	0.22	-0.43
P =	0.047	0.001
ADF intake		
r =	0.13	-0.48
P =	0.259	0.001
DMD		
r =	-0.01	0.11
P =	0.992	0.337
Starch digestibility		
r =	-0.14	0.10
P =	0.200	0.380
ADF digestibility		
r =	0.06	-0.10
P =	0.599	0.355

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APPENDIX A

ANALYSIS OF VARIANCE TABLE

Table 1. Sample SAS output for average daily gain

Dependant Variable: ADG

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	23	5.42322	0.235792	7.83	0.0001
Error	56	1.68576	0.030103		
Corrected Total	79	0.3865800			

R-Square	C. V.	Root MSE	ADG Mean
0.76287	11.41834	0.1735017	1.51950

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	1	0.0858050	0.0858050	2.85	0.0969
Period	4	4.5724675	1.1431168	37.97	0.0001
Treatment	3	0.0633800	0.0254860	0.70	0.5549
Per*Trtmt	12	0.3058325	0.0254860	0.85	0.6035
Block*Trtmt	3	0.3957350	0.1319117	4.38	0.0077

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
LB57 vs parents	1	0.0040833	0.0040833	0.14	0.7140
LB6 vs parents	1	0.0005633	0.0005633	0.02	0.8917