EFFECT OF BEEF CATTLE AGE, GENDER AND BARLEY GRAIN PROCESSING METHOD ON RATE AND EFFICIENCY OF GAIN AND NUTRIENT DIGESTIBILITIES

by

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ABSTRACT

Three experiments were conducted to test the effects of animal age (cows vs. calves) and barley processing method (whole vs. rolled) on rate and efficiency of gain and diet digestibility when barley was fed as a supplement to medium quality grass hay. A fourth experiment was conducted to test the effects of differences in diet composition on ADG and carcass characteristics in early-weaned calves. No age x processing interactions ($P > 0.05$) were detected for OM, N, ADF or NDF digestibilities. Diet OM and N digestibilities were greater ($P < 0.01$) when consumed by calves compared to cows, but ADF and NDF digestibilities were similar between ages. A processing method x age interaction was measured ($P < 0.05$) for starch digestibility. Rolling the barley dramatically improved starch digestibility when fed to cows (71.4% vs. 23.3% for rolled vs. whole). For experiment two, animals fed the hay only diet had similar ($P > 0.05$) rates and efficiencies of gain as diets supplemented with barley. Barley processing had no effect ($P > 0.05$) on rate or efficiency of gain for cows or calves. Cows were less efficient than calves (12.6 vs. 7.6) when fed similarly formulated diets. Unlike experiment 1, no differences were measured for digestibility of OM, N, ADF, NDF, or starch due to animal age or grain processing method. For experiment 4, calves fed barley gained faster (1.29 $kg \cdot d^{-1}$ vs. 0.99 $kg \cdot d^{-1}$; $P = 0.002$) and had higher marbling scores (4.44 vs. 3.31 %EEF; $P = 0.002$) compared to calves fed wheat midds during the first 34 d after weaning. However, gains during the 90 d after weanining were nonsignificant (1.36 vs. 1.24 $kg \cdot d^{-1}$ for barley and midds respectively). Calculated final live weights and marbling scores after 217 d of consuming a common finishing ration were similar for barley-fed calves compared to wheat midds-fed calves. Results suggest processing of barley may be of greater value for mature cows compared to younger calves, and barley had a greater effect on changing calf body composition than wheat midds. $Cost \cdot kg^{-1}$ gain was similar for whole vs. rolled barley diets.

INTRODUCTION

The marketing criteria for barley were established under the United States Grain Standards Act of 1916. Currently, barley is defined as grain before the removal of dockage and consists of 50 percent or more of whole kernels of cultivated barley (*Hordeum vulgare* L.) and not more than 25 percent of other grains for which standards have been established (Montana Wheat and Barley Committee, 1999). Barley is divided into two primary classes; malting or feed grain quality. Malting barley is further divided into three subclasses which are defined as any barley that does not meet the requirements for the subclasses of six-rowed or two-rowed barley's. Visual evaluation is the simplest method of measuring barley grain quality however; this approach lacks consistency among evaluators. Therefore, weight per volume has been considered the next best method of barley evaluation (Hinman and Sorensen 2001).

The nutritive value of barley is primarily in its energy value, with protein being of secondary importance (Hunt 1996). Barley contains lesser amounts of dietary energy compared to corn because of increased protein and fiber content, therefore making it more expensive per unit of energy and less attractive for use in feedlot rations. Barley has a greater extent of ruminal starch digestion (Theurer, 1986; McCarthy et al., 1989; Overton et al., 1995) than corn. Numerous studies have compared the feeding value of barley to corn (Owens et al., 1997). Despite the lower energy content of barley, any similarities in performance between barley and corn were likely a result of the more complete starch digestion of barley from a higher microbial protein production in the rumen (Alberta Feedlot Management Guide, 2000) due to barley having a higher protein value. However, one negative aspect of barley-based diets is a tendency for decreased ruminal pH resulting in an increase in the incidence of acidosis and (or) bloat, compared to corn-based diets (Orskov, 1986; Owens et al., 1986).

Barley is often fed as a supplemental energy source to cattle in the western United States and Canada because it is extensively grown, readily available, and less expensive than corn and other cereal grains (Feng et al., 1995). Much of this lower cost/ton can be attributed to lower shipping costs compared to Midwest-grown corn.

Varietal differences, soil fertility and climatic conditions have all been reported to influence the nutrient content of barley (Boyles et al., 2000). Test weight has been adopted as a means of accounting for varying densities of grain caused by weather and(or) production practices. If grain density is lower than the accepted standard, more volume is needed to store and transport a given weight of grain, which results in increased storage and transportation costs (Beuerlein 2002), and low test weight barley is discounted when sold. There are two common causes of low test weights. First, grain is prevented from filling completely and (or) maturing and drying naturally in the field due to a killing frost, hail, or secondly insect damage, or the grain matures and dries naturally in the field but is rewetted by rainfall, dew, or fog causing the grain to initiate precocious germination before harvesting (Beuerlein 2002). Minimum grading requirements for feed barley are; U.S. No. 1 = 21.4 $kg{\cdot}bu^{-1}$, U.S. No. 2 = 20.5 $kg{\cdot}bu^{-1}$, U.S. No. 3 = 19.5 $kg{\cdot}bu^{-1}$, U.S. No. 4 = 18.2 $kg{\cdot}bu^{-1}$, and U.S. No. 5 = 16.4 $kg{\cdot}bu^{-1}$ (Montana Wheat and Barley Committee, 1999).

Traditionally as barley test weight decreases, protein and fiber levels increase while starch decreases (Hinman and Sorensen 2001). Furthermore, feed conversion (F:G) tends to increase linearly as test weight decreases. Hinman and Sorenson (2001) reported that daily gain decreased linearly as bulk density decreased. Daily gains were fastest for the heaviest weight barley and slowest for the light test weight barley. Diet DMI was not affected by barley bulk density, but feed efficiency was improved.

Montana beef producers have raised questions about the feeding value of light test weight barley caused by prolonged drought conditions. Ranchers are faced with the decision of either using light test weight barley as an energy supplement in their rations for beef cows and calves or enduring “dockage” for the lower quality feed grain. In addition, a second question is whether there is a need to process the light test weight barley or if it is possible to feed the grain whole without causing detrimental effects on performance. The lack of accessible grain processing equipment makes it difficult for producers to justify transportation costs in addition to the processing cost for the barley (estimated to be $10-20/ton for rolling). Extensive research has been conducted testing the differences in feeding normal test weight whole vs. processed barley. The objectives of this research were to evaluate beef cattle age and barley processing method on efficiency of nutrient digestion and growth and to compare performance of early-weaned calves supplemented with either light test weight barley or wheat middlings.

LITERATURE REVIEW

Light vs. Regular Test Weight Barley

Animal Performance

Barley that has a lighter than normal test weight can be a direct result of drought. Seasonal weight variation has no effect on NE_m content (Suleiman and Mathison 1979) and depending upon the analytical method used, these researchers estimated the NE_m content of barley to be between 1.82 and 1.91 $Mcal \cdot kg^{-1}$ of DM, which was similar to values reported by the 1996 NRC (1.85 and 2.06 $Mcal \cdot kg^{-1}$ respecitvely). Usually, light test weight barley is a less expensive source of dietary energy compared to higher quality, heavier test weight barley, but still may be an excellent source of supplemental energy. Table 1 compares recent values calculated by Bowman (2001) to 1996 NRC values. Bowman's protein (N), NE_m, NE_g, and Ca were higher for light test weight barley compared to NRC (1996). Light test weight barley had lower P, Zn, and Cu than reported NRC values for light and heavy test weight barley's.

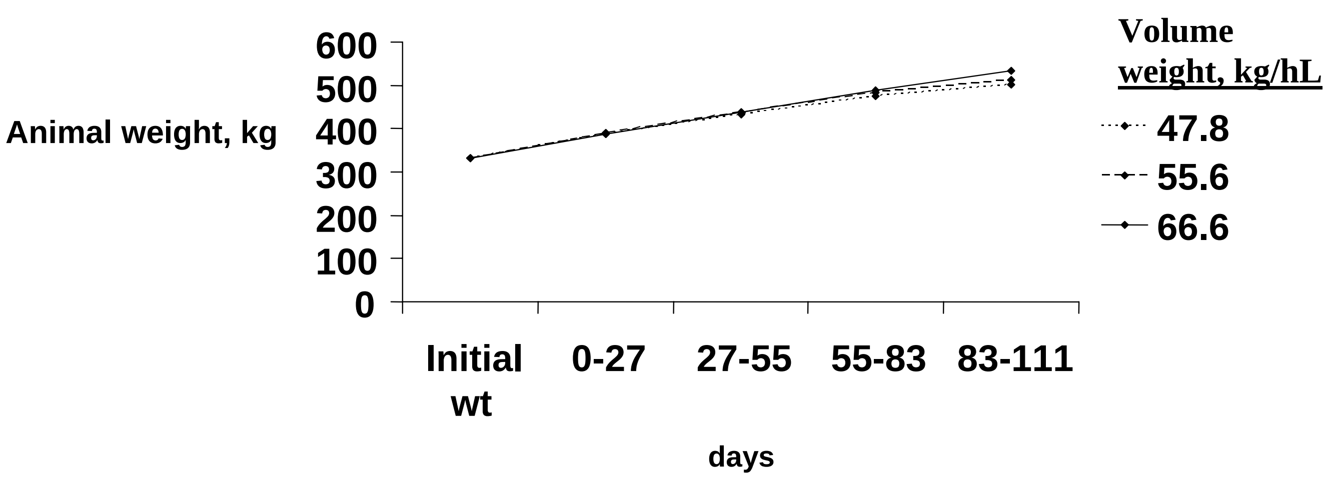
Table 1. Nutrient comparison of light and heavy test weight barley grain (DM basis) compared to published National Research Council (NRC) values.

	NRC (1996)		Bowman (2001)	
Nutrient	**Light Test weight**	**Heavy Test weight**	**Light Test weight (19 kg·bu^{-1})**	**Heavy Test weight (24kg·bu^{-1})[a]**
DM, %	88.00	88.10	92.20	92.30
N, %	2.24	2.11	2.64	2.11
ADF, %	--	5.8	7.8	5.0
Starch, %	--	--	42.58	54.20
NE_m, Mcal/kg	1.85	2.06	1.96	2.35
NE_g, Mcal/kg	1.22	1.40	1.30	1.65
Calcium, %	0.06	0.05	0.92	--
Phosphorous, %	0.39	0.35	0.26	--
Zinc, ppm	44.4	13.0	22.0	--
Copper, ppm	8.6	5.3	6.0	--

[a]Adapted from Bowman (2001)

Thomas (1962) tested the effects of light (20 kg·bu^{-1}) to heavier test weight (23 kg·bu^{-1}) barley in high concentrate diets fed to Hereford steers and found no differences in ADG. Similarly, Bowman (2001) compared light (19 kg·bu^{-1}) to heavy test weight (24 kg·bu^{-1}) barley for backgrounding calves and also found no differences in rate or efficiencies of gain due to test weights. Hinman (1978) reported no differences in the DMI between light and heavy test weight barleys fed to beef cattle, and only a slight advantage in ADG and feed efficiency (8.8 and 6.6% respectively) for the heavy weight barley was measured. Grimson et al., (1987) measured the effects of barley volume-weight on feedlot performance over 111 d for finishing steers and found no differences in ADG or DMI for steers fed diets containing 85% barley of three different volume-weights (light, 47.8; medium, 55.6; heavy, 66.6 kg·hL^{-1}; Figure 1).

Figure 1. Changes in body weight for steers fed light, medium or heavy test weight barley in a 111 d experiment (adapted from Grimson et al., 1987)



In an 83-d trial using 90 Hereford steers fed diets of 90.3% concentrate and 9.7% alfalfa hay (DM basis), Mathison et al., (1991b), found no differences in ADG, DMI, or feed efficiency for three different test weight barleys (15, 21 and 23 kg·bu^{-1}; Table 2).

Table 2. Effect of barley volume-weight on steer performance and carcass traits (adapted from Mathison et al., 1991b)

	Volume-weight (kg·hL^{-1})			
Item	**43**	**59**	**64**	**SE**
No. animals	30	30	29	
Initial wt.	394	395	393	2.3
Final wt.	528	531	527	5.1
Daily gain, kg	1.63	1.67	1.65	0.05
DMI, kg·d^{-1}	10.21	9.87	9.84	0.21
Feed:gain	6.29	5.89	6.00	0.17

Diet Digestibility

A digestibility study was conducted by Mathison et al., (1991b) using steers fed at either high or low intake levels. At a low level of intake, fiber digestibilities were lowest for the 64 kg·hL^{-1}, and DMD was lowest ($P < 0.05$) for the 64 kg·hL^{-1} test weight barley as well as the barley weighing 43 kg·hL^{-1}. At the highest level of intake barley DM, OM, and ADF digestibilities were greater ($P < 0.05$) for the 64 kg·hL^{-1} than for the 43 kg·hL^{-1} treatment. Across both feeding levels, steers fed the lightest barley digested 2 % less ($P < 0.05$) OM than steers fed the three heavier barley grains, and CP digestibility was lowest ($P < 0.05$) for the lightest barley compared to the 64 kg·hL^{-1} treatment. No differences were detected for fiber digestibilities among diets containing the different barley grains. Combined results for high and low levels of intake and apparent digestibility are summarized in Table 3.

Table 3. Effect of barley volume-weight on apparent digestibility (adapted from Mathison et al., 1991b)

	Volume-weight of barley ($kg \cdot hL^{-1}$)				
Item	**43**	**59**	**64**	**66**	**SE**
Steer wt, kg	300.0^{a}	339.4^{b}	301.3^{a}	323.8^{b}	6.11
Both intakes					
DMI ($g \cdot kg^{-0.75} \cdot d^{-1}$)	52.7	55.3	53.6	54.5	0.75
Apparent digestibility, %					
DM	79.9^{a}	82.1^{b}	81.8^{b}	82.2^{b}	0.59
OM	81.3^{a}	83.5^{b}	83.1^{b}	83.4^{b}	0.58
ADF	32.4	27.7	28.3	33.0	2.51
NDF	42.0	33.8	36.9	37.1	2.39
Crude Protein	72.7^{a}	75.6^{ab}	77.2^{b}	75.1^{ab}	0.93
Low intake					
DMI ($g \cdot kg^{-0.75} \cdot d^{-1}$)	39.2	38.8	39.2	38.8	0.20
Apparent digestibility, %					
DM	81.2^{a}	83.9^{b}	80.9^{a}	84.3^{b}	0.86
OM	82.5	85.1	82.4	85.6	3.51
ADF	33.9^{a}	33.9^{a}	21.7^{b}	37.1^{a}	3.51
NDF	45.2^{a}	45.2^{a}	33.5^{b}	48.6^{a}	3.41
Crude Protein	76.0	77.4	76.8	79.2	1.17
High intake					
DMI ($g \cdot kg^{-0.75} \cdot d^{-1}$)	69.5	71.8	71.5	70.2	1.71
Apparent digestibility, %					
DM	78.3^{a}	80.3^{ab}	82.9^{b}	80.1^{ab}	0.91
OM	79.9^{a}	81.9^{ab}	84.0^{b}	81.2^{ab}	0.91
ADF	30.4	28.7	36.4	29.0	4.01
NDF	38.0^{ac}	29.0^{ab}	41.2^{c}	25.5^{b}	3.72
Crude Protein	68.6^{a}	73.8^{ab}	77.6^{b}	71.0^{a}	1.65

^{abc}Within a row means without a common superscript letter differ $P < 0.05$

Results from Table 3 suggest that heavier weight barley may decrease fiber digestibilities at low levels of intake. However numerical decreases for fiber digestibility were shown at higher levels of intake vs. lower intake levels and suggested that the depression in fiber digestion may be of greater concern when barley is fed at ad libitum intakes.

Digestive Upsets

Comparing three barley test weights Mathison et al., (1991b) observed a 12% occurrence of bloat (Table 4) in Hereford steers fed either dry- or steam-rolled barley in 90% (DM basis) concentrate rations. Heavy test weight barley was more slowly degraded by enzymatic action in vitro and coincidentally had the least number of bloats. Likewise, light and medium test weight barley had similar rates of starch degradation and resulted in a similar number of bloats. Starch in steam-rolled barley was more susceptible to degradation than dry-rolled barley and also resulted in a slightly higher percentage of bloats. Van Ramshorst and Thomas (1988) found that decreasing the rate of starch degradation with formaldehyde treatment increased passage of both starch and protein to the small intestine in sheep. If a smaller portion of the lighter test weight barleys and dry-rolled barley in Mathison's study escaped the rumen then greater rumen retention times may explain the increased incidence of bloat.

Table 4. Occurrence of bloat due to bushel weight and processing method

	Volume-weight ($kg \cdot hL^{-1}$)			**Grain rolling method**	
Item	**43**	**59**	**64**	**Dry**	**Steamed**
No. animals	30	30	29	47	48
No. bloated animals	4	5	2	5	6

[a]Adapted from Mathison et al., (1991b)

Whole vs. Processed Grains

Animal Performance

Light test weight barley usually has a greater variation in kernel size than heavy weight barley and makes it more difficult to process than barley of uniform kernel size (Hinman and Sorensen 2001). The majority of energy in finishing cattle diets is supplied by starch (Boyles, 2000). Ninety percent of barley starch is fermented in the rumen, and barley is provided to increase intake and energy density in the diets of cattle (Orskov, 1986). The addition of whole grain supplements generally results in a decrease in performance compared to processed grains because rumen microbes cannot penetrate the pericarp of whole grain (Alberta Feedlot Management Guide, 2000). Owens et al., (1997) summarized 605 feeding studies. Interestingly the summary showed no differences ($P > 0.05$) when comparing whole vs. processed barley grain for rate of gain, DMI, F:G and ME in feedlot diets for cattle (Table 5).

Table 5. Comparison of whole vs. rolled barley grain on the effects of ADG, DMI, F/G and ME in feedlot diets (adapted from Owens et al., 1997)

	Barley processing method	
Item	**Whole**	**Rolled**
Rate of Gain (kg/d)	1.38	1.45
DMI (kg/d)	9.30	8.96
Feed efficiency (feed/gain)	6.66	6.25
ME ($Mcal \cdot kg^{-1}$ DM)	2.85	3.40

Bowman, (2001) recommended that generally if barley addition is greater than 50% of the diet, it should be processed. Howerver, Campling (1991) suggested that whole grain can be adequately digested by calves and growing cattle. However, supplementing lesser amounts to forage-based diets to increase diet energy value should be evaluated based on cost in relation to the difference in rate and efficiency of gain Bowman, (2001). However, Campling (1991) concluded that even with high forage diets, barley processing increased starch digestibility and performance for growing cattle.

Axelsen et al., (1979) found cattle fed cracked wheat had a 32% greater live weight gain compared to cattle fed whole wheat at restricted intakes. However, when diets were offered ad libitum, gains were similar. Mathison (1996) suggested that when feeding whole barley, rate of gain could be reduced by 5-50% and the amount of feed required per unit of gain increased by 15-100% when whole barley replaced rolled barley. In a 56-d study, Mathison (1996) found that steers fed either 33% or 67% concentrate diets did not increase intakes enough to maintain maximum intake of energy (ME = 84.7 vs. 81.4 $MJ \cdot d^{-1}$; rolled vs. whole), and feed efficiencies declined accordingly. This may have been due to the failure of rumen micro-organisms to attach to the intact cereal seeds and was probably related to the nature of the outer covering of the grains (Nordin and Campling 1976).

Diet Digestibility

Grain that is fed whole tends to have a lower digestibility than processed grain (Morgan and Campling, 1978; Mathison, 1996). Processing methods were originally developed to improve starch and protein digestibility of the grain (Boyles, 2000) and reduce the need for more extensive mastication by the animal. Processing grain has increased the rate and extent of ruminal starch digestion (Cheng et al., 1998), because ruminal microbes do not penetrate whole grain or only do so very slowly (Orskov 1986). Toland (1976) suggested that it was not unreasonable to speculate that the lower digestibility of whole barley and higher proportion of voided grain may be accentuated by the grain's resistance to fracturing during the digestive processes when fed to cattle.

Nicholson et al., (1971), Ahmed et al., (1973), and Morgan and Campling (1978) found that OM digestibility was decreased when whole barley was fed compared to dry rolled barley. Toland (1976) conducted three different experiments with diets based on oats, barley and wheat. Twenty-four, two year old Hereford steers were tested in a cross-over design to determine differences in digestibility of whole vs. rolled grain. Dry rolling barley increased OM digestibility 42% and starch digestibility 100% (Table 6) for barley grown in drought like conditions. The seasonal growing conditions also resulted in relatively higher N and lower starch content for the grain than would be expected (2.66 and 46.8% respectively; DM basis; Toland, 1976).

Table 6. Ration and grain digestibility and improvement due to rolling (adapted from Toland, 1976)

Item	Whole	Rolled	Improvement[a]
Oats diet	--------------------%--------------------		
OM	69.4	72.2	4.0
Starch	93.4	99.1	6.1
Oat grain			
OM	76.7	81.0	5.6
Barley diet			
OM	53.0	75.2	41.9
Starch	49.4	98.8	100.0
Barley grain			
OM	52.5	85.2	62.3
Wheat diet			
OM	60.2	76.9	27.7
Starch	62.0	99.0	59.7
Wheat grain			
OM	62.9	87.7	39.4

[a]Improvement = (rolled –whole) / whole

Likewise Morgan and Campling (1978) reported a 49% decrease in starch digestibility with whole barley, while Mathison (1996) found a 37% average decrease in starch digestibility when whole was compared to rolled barley for cattle.

Orskov (1986) suggested that the least amount of mechanical processing necessary while still maintaining acceptable digestibilities was best for animals in terms of health cost and animal performance. Plus unlike sorghum grain or corn, there is little improvement in barley starch digestion from extensive processing beyond dry rolling (Theurer 1986).

Effects of Grain Supplementation on Fiber Digestion

When grain exceeds 20-30% of the ration it can depress intake to such an extent that it no longer is considered a supplement but rather is a substitute for forage (Orskov 1986). Supplementation and substitution may cause reductions in forage intake by grazing and pen-fed ruminants, however energy supplementation can be very desirable at times, based on factors of forage quantity and quality and production demands (Caton and Dhuyvetter, 1997). This is especially true if grazed forage energy levels are low.

Supplementation may cause reduced forage intakes in grazing situations (Lusby and Wagner, 1986; Chase and Hibberd, 1987; and Pordomingo et al., 1991). However, Matejovsky and Sanson (1995) observed increased intakes by sheep supplemented with low levels of grain when consuming forage based diets.

Associative effects or, interactions among feeds, often lead to under- or overvaluation of supplements. If negative associative effects on cell wall digestibility were to occur it would probably be when concentrate supplementation was provided between 0.4 and 0.6% of BW (Pordomingo et al., 1991). Caton and Dhuyvetter (1997) suggested that supplemental barley fed at 0.8% of BW would only marginally affect forage intake and digestibility of steers, which also concurs with work by Horn and McCollum (1987) who suggested that energy supplementation at 0.7% of BW would minimally affect forage utilization. Ovenell et al., (1991) observed total diet DMD to be increased by supplementation of forage diets with a concentrate. Numerous studies showed that higher fiber digestibilities along with lower starch digestion would be more favorable for increasing intake and total tract digestibilities (McDonnel et al., 1982; Klopfenstein et al., 1985; and Bernard et al., 1988), and a greater percent of starch may escape rumen degradation if fibrous roughages form part of the diet (Orskov 1986).

Cellulose, hemicellulose, pectins, and lignin, along with the matrix interactions are the major determinants of the rate and extent of cellulose utilization by the ruminal microbial population (Weimer, 1992). Additionally, noncellulolytic microorganisms either directly or indirectly affect the nutritional status and metabolic activity of the cellulolytic population (Weimer, 1992). Many times, during supplementation or intensive feeding systems in which rapidly degraded substrates such as starch or sugars are fed, rumen pH often falls below optimum levels for cellulases (Orskov, 1991). This was demonstrated by Mould et al. (1982), who showed that if rumen pH reached a level below approximately 6.2 then cellulolysis was reduced. The result was up to a 40% reduction in digestibility of hay. High concentrate diets fed with extensively processed grains resulted in inadequate saliva thereby reducing buffering capacity to maintain normal rumen pH of 6.0-7.0 (Orskov 1986). This potentially leads to an increase in the incidence of digestive disorders. High concentrate diets lack the physical structure needed to stimulate ruminal motility; however this tends to not be as much of concern for supplemented diets for grazing animals (Orskov 1986).

Fahmy et al., (1984) found the digestibility of ammoniated straw was unaffected at low levels of barley supplementation, but showed a reduction from 53 down to 23%

digestibility when including 700 g of rolled barley/kg of BW to a basal diet of 300g of ammoniated straw vs. that of a straw only diet. However, Morgan and Campling (1978) found that cellulose digestibility was not influenced by rolled barley and digestibility of DM and starch were increased by 33 and 100% respectively compared to whole barley. Ahmed et al., (1973) observed that a greater depression in fiber digestion occured when forage diets were supplemented with rolled grain compared to whole grain. Furthermore, Mathison (1996) found that whole barley was 10-30% less digestible than dry-rolled barley, with the proportion of forage in the diet having little influence on the digestibility of whole grain.

Occurrence of Undigested Feed Found in Feces

Orskov (1986) reported that when whole grain was transferred to the post ruminal tract a large portion of the nondigested grain appeared in the feces and was as high as 30% of that fed in the diet. Observations of Toland (1976) reported that the number of whole grain kernels found in feces is directly related to the undigested starch in the feces of cattle fed oats, barley, and wheat. Mackintosh (1971) found an average of 48 percent by weight of grain in the feces when whole barley was supplemented in the diets of two-year-old steers. However, a study by Shaw and Norton (1906) found that the amount of whole oats passing through cattle varies with age, as only three percent passed through calves, while 12 percent passed through cows. Beauchemin et al., (1994) wet –sieved subsamples of fecal composites and observed between 21 and 37% of grain particles isolated from the feces of cattle fed whole cereal grains to be retained on a 1.18-mm screen. The largest retention was observed for wheat; however, more than 75% of the retained barley and wheat kernels were whole (Table 7).

Table 7. Characteristics of grain particles isolated from the feces of cattle fed whole cereal grains (adapted from Beauchemin et al., 1994)

Item	Barley	Corn	Wheat	SEM
DM retained on 1.18-mm screen % of fecal DM	20.6[b]	21.9[b]	36.8[c]	3.5
	% of DM retained on a 1.18-mm screen			
Proportion[a]				
Whole	75.0	49.5	82.4	10.5
Damaged	2.8[b]	12.7[c]	4.5[bc]	2.1
Broken	8.7	26.5	9.8	7.8
Empty	13.5	11.2	3.2	4.4

[a]Fractions described as whole (kernels with no visible damage to the pericarp), damaged (pericarp damaged but kernel intact), broken (kernel fractured into pieces), or empty (fractured pieces of the pericarp containing no endosperm).
[b,c]Means within a row with different letters are significantly different at the 10% level of probability

An in sacco study by Beauchemin et al., (1994) may explain the lack of mastication by these cattle because they found unchewed whole grains to be relatively indigestible, as less than 30% disappearance was observed after 96 h of ruminal incubation. Also, smaller differences have been detected for rolled barley digestibilities among cows, compared to a much greater variation found in cows fed whole barley (Nordin and Campling 1976). Furthermore, Beauchemin et al., (1994) observed cattle to be more effective at chewing diets containing corn as they were less aggressive at the bunks than observed with other cereal grains. Therefore, eating behavior could correspond to differences in both the extent of ruminal and total tract digestibilities and the amount of bypassed whole grain excreted in the feces. Beauchemin et al., (1994) also suggested that these differences in ingestion of various cereal grains corresponded to time spent ruminating because longer eating times with corn corresponded to less rumination activity and shorter eating times for barley and wheat was related to more rumination. Differences existed in the starch and fiber digestibilities within barley varieties, as reported by Harrison (1999), who found the range from a low of 87.9% for Baroness to a high of 96.2% for Idagold.

Effect of Animal Age on Grain Utilization

Campling (1991) indicated that definitive evidence was not clear concerning the effect of animal age on digestion of whole grain. Because younger cattle are more efficient masticators, they should digest whole grain to a greater extent than older cattle (Nicholson et al., 1971; Morgan and Campling, 1978). Beauchemin et al., (1994) observed mastication differences between different feeds; whole corn was found to be substantially damaged after ingestive mastication whereas many barley and wheat kernels remained intact. However, Kimberly (1976) found no differences in digestion of whole grain for cattle ranging from 6 to 24 mo of age. Younger cattle tended to digest a higher percent of starch in cereal grains than did older cattle. Furthermore, Beauchemin et al., (1994) found that cattle fed whole barley spent twice as long ruminating per kg of DM as those fed corn, with wheat being an intermediate. Toland (1976) reported that there continues to be a need to define the utilization of processed and unprocessed grain as influenced by animal age. If whole grains are not physically damaged from mastication then digestion was severely depressed (Orskov et al., 1978; McAllister et al., 1990).

Bloat and Potential Prevention by the Use of Ionophores

To reduce the incidence of bloat when feeding high concentrate diets. Bowman (2001) suggested such management strategies as the addition of monensin to diets at levels of 320 to 360 mg per animal per day, increasing the frequency of feeding to two times per day, feeding animals within 15 min of the same time every day, and not using barley in conjunction with alfalfa hay may be helpful in reducing bloat.

Various carboxylic polyether ionophores are often fed to cattle to help reduce the incidence of ruminal acidosis and bloat. The various ionophores are produced by strains of Streptomyces and include monensin, lasalocid, salinomycin and narasin (Bergen and Bates, 1984). While controlling ruminal disorders, ionophores are also used to improve feed efficiency. In diets that contain high levels of readily fermentable carbohydrates, ionophores improve gain/feed by depressing feed intake but not ADG. When ruminants are fed diets containing considerable amounts of structural carbohydrates, ionophores do not depress intake, body weight gain is improved, and this results in improved feed efficiency (Bergen and Bates, 1984).

In batch culture experiments Kung et al., (1992) found that 33 ppm (DM) of lysocellin decreased pH and methane production but had no effect on fiber digestion. In one study monensin was found to have no effect on ruminal OM and starch digestion (Zinn 1987), but in several studies monensin decreased ruminal digestion of OM

(Muntifering et al., 1981; Zinn and Borques, 1993) and starch (Muntifering et al., 1981). Kung et al., (1992) discovered differences in OM digestion for corn based diets, whereas OM digestion was suppressed for barley based diets. Surber and Bowman, (1998) suggested that differences in OM and starch digestibility may be explained by different grain sources which respond differently to the addition of ionophores in the diets. Not only may differences occur between grains, but also certain barley lines have been found to respond differently with the addition of monensin on IVDMD (Surber and Bowman, 1998). These researchers found monensin addition increased IVDMD of Gunhilde and of Medallion at 3, 6, and 9 h of incubation, but decreased IVDMD of Harrington barley. Differences within these barley lines were less significant beyond 9 h of incubation. Although differences occurred for IVDMD in these studies an in vivo study found no difference in the flow of starch to the abomasum or in ruminal starch digestion. Bergen and Bates, (1984) suggested that ionophores improve efficiency of production for growing and finishing cattle by increasing efficiency of energy metabolism in the rumen and(or) animal, improve N metabolism in the rumen and(or) animal, and provide retardation of feedlot disorders, especially lactic acidosis (chronic) and bloat. They further implied that all of the observable effects of ionophores are a secondary phenomena from the disruption of normal rumen membrane physiology.

Early Weaning of Beef Calves

Advantages of Early-Weaning Beef Calves

The response to early weaning of beef calves has been well documented (Fluharty et al., 2000; Story et al., 2000; Barker-Neef et al., 2001), however none of these studies included the use of light test weight barley as a primary energy source in the diet. Early weaning has been practiced after periods of drought, in which forage availability may be limited and energy requirements are greater for the cow due to lactation. Early weaning has many positive attributes which include a greater percentage of calves that graded Choice or higher (Myers et al., 1999), heavier weight calves at 210 d of age compared to normal weaning (Fluharty et al., 2000), better feed conversions (Myers et al., 1999), resulting in a lower cost of gain (Barker-Neef et al., 2001), as well as younger calves at slaughter (Peterson et al., 1987; Makarechian et al., 1988). Cow reproductive performance has been improved because cow weight and condition scores were increased due to early weaning calves (Short et al., 1996; Arthington and Kalmbacher, 2003). The acceptance of early-weaning in production practices may be influenced primarily by feed and housing resources for animals.

Effects of Early-Weaning on Ruminal Environment and Growth

Conventional weaning occurs at approximately 7 mo of age, whereas early weaning may occur after 6 wk of age. Anderson et al., (1987) found that calves weaned at less than 6 wk of age had a higher concentration of total ruminal volatile fatty acids and a lower ruminal pH when fed a highly palatable pre-starter diet from 3 d of age to weaning. Prolonged milk feeding delayed the onset of typical ruminal microflora Lengemann and Allen, (1959) and establishment of protozoa (Singh, 1972). These results suggest that rumen microbes adapted to the available substrates, making it possible to feed calves diets that were similar in energy content to growing and finishing cattle diets.

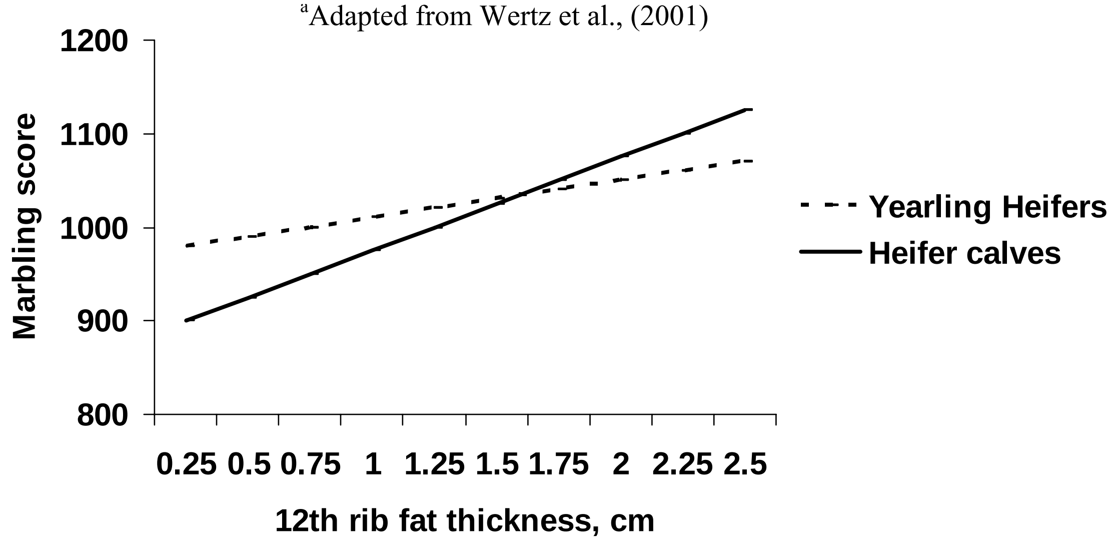
Fluharty et al., (2000) compared calves weaned at approximately 93 d of age vs. 210 d and found that calves fed a diet of 90-100% concentrate were heavier at 210 d of age, had a greater backfat thickness, with no detrimental effects on longissimus muscle area compared to calves fed a 60% concentrate diet. Furthermore, steers weaned between 158 and 177 d of age and placed directly onto a finishing diet gained 100% faster than normally weaned steers which were allowed grazing time with their dams prior to being placed on the finishing diets (Myers et al., 1999).

Effects of Diet Composition on Changes in Fat Deposition of Early-Weaned Calves

Prior (1983) showed that adipocytes remained smaller but became more numerous within the longissimus muscle area for grain diets compared to forage-based diets of cattle. Cianzio et al., (1985) found that marbling score was correlated more with the number of adipocytes·gram^{-1} of tissue rather than the diameter of the adipocytes themselves. They further suggested that fat cells/gram of tissue is a slightly better single predictor of marbling score, yet the combination of cell number and cell size improved the prediction of marbling (R^2 = 0.63). Earlier work by Cianzio et al., (1982) suggested that lower subcutaneous fat thickness did not necessarily predict reduced marbling, and that intramuscular fat was not a late developing tissue. It was suggested that a simple measurement of this characteristic at a young age could be used to predict the potential for the animal to express marbling during later growth phases. However, Wertz et al., (2001), regressed marbling score on 12th rib fat thickness (based on ultrasound) for early-weaned heifers that were grazed on pasture before entering the feedlot as yearlings vs. those grown in the drylot and finished as calves. For both groups, marbling scores increased linearly as 12th rib fat thickness increased. Marbling score slope increase was steeper relative to 12th rib fat thickness for heifers finished as calves compared to heifers finished as yearlings (Figure 2).

Figure 2. Regression of marbling score on 12th rib fat thickness

[a]Adapted from Wertz et al., (2001)



Dietary Ingredients for Early-Weaned Calves

Growing and finishing diets for early-weaned calves have been primarily composed of corn (Myers et al., 1999; Fluharty et al., 2000; Wertz et al., 2001). Barley contains lesser amounts of dietary energy compared to corn because of increased protein and fiber content. However, barley also exhibits a greater extent of ruminal starch digestion (Theurer, 1986; McCarthy et al., 1989; Overton et al., 1995) and any similarities in performance between the two grains is likely due to the more complete starch digestion from a higher microbial protein production (Alberta Feedlot Management Guide, 2000). Furthermore, in an evaluation of finishing cattle, Owens et al., (1997) reported no differences in DMI or rate and/or efficiency of gain for cattle fed high concentrate diets of barley, corn, or wheat across various processing methods (Table 8).

Table 8. Least squares means for grain types fed to finishing cattle averaged across various processing methods (adapted from Owens et al., 1997)

Item	Barley	Corn	Wheat
ADG, kg	1.42	1.43	1.38
DMI, kg/d	8.77	8.93	8.65
Feed:gain	6.24	6.32	6.34

Wheat Middlings

Wheat middlings comprise a major portion of the by-product from flour milled in the United States (Dalke et al., 1997). The nutrient content of wheat middlings can be highly variable (Dalke et al., 1997), but contains approximately 1.6 Mcal $NE_m \cdot kg^{-1}$ and

1.0 Mcal $NE_g \cdot kg^{-1}$, 18.0% CP, and high levels of rapidly degradable fiber (NRC, 1984). Wheat middlings in high concentrate diets may improve nutrient availability when fed at restricted levels (Hermesmeyer et al., 2002). However, due to the lower energy value, Dalke et al, (1997) found that wheat middlings could only replace up to 5% of dry rolled corn in high concentrate diets without being detrimental to feed conversion efficiency and diet digestibility. However, Brandt et al., (1986) reported no reduction in the rate and efficiency of gain for finishing diets of steers when pelleted wheat middlings replaced approximately 10% of dry rolled corn

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MATERIALS AND METHODS

Experiment 1 - Effect of Animal Age and Barley Grain Processing Method on Diet Digestibilities of Beef Cattle

Objectives

The objectives of these experiments were to determine the effects of animal age (cows vs. calves), and barley processing method (whole vs. rolled), on diet and nutrient digestibilities when fed as a supplement for medium quality grass hay.

Animals/Treatments

Sixteen, 31 mo old, pregnant (second trimester) Angus crossbred cows (532 ±27 kg) and 16 recently weaned steer calves (245± 24 kg) were used in this 25-d digestion experiment. Dietary treatments were arranged in a 2 x 2 factorial design testing the main effects of animal age (cows vs. calves), barley processing method (whole vs. rolled) and the interaction of age and processing method. The diets consisted of light test weight barley (19 $kg\cdot bu^{-1}$), medium quality grass hay (10.8% CP; 39.2% ADF, DM basis), and a commercially produced 36.7% protein and mineral supplement. The diets were formulated to be isonitrogenous (12.6% CP) and isocaloric (1.48 $Mcal\cdot kg^{-1}$ NE_m, 0.83 $Mcal\cdot kg^{-1}$ NE_g).

Barley was fed at 0.5% of BW because Pordomingo et al., (1991) suggested that negative associative effects may occur when corn supplemention level was between 0.4 and 0.6% of BW (2.5 $kg\cdot cow^{-1}\cdot d^{-1}$ and 1.15 $kg\cdot calf^{-1}\cdot d^{-1}$, DM basis). Hay was provided to cows at 1.5% of BW and to calves at 2.1% of BW, DM basis. All animals received 0.20 $kg \cdot hd^{-1} \cdot d^{-1}$ of the CP, mineral supplement.

A 10 d acclimation period was used to adapt animals to individual electronic feeding gates (Calan Gates, American Calan, Northwood, NH), and waterers. There were eight pens with four animals per pen (four pens contained cows, four pens contained calves). Both cows and calves were randomly assigned to diets containing either whole barley or rolled barley with each pen containing two animals receiving each of the two treatments. Starting on d 1 and continuing through d 25, all animals were fed their respective diets at approximately 0700 h. Beginning on d 14 and continuing through d 24, all cattle were individually dosed with a gelatin capsule containing 10g of chromic oxide to estimate fecal output. Fecal grab samples were collected from d 22 through d 25 at the time the chromic oxide was administered (1400 h). Feed samples were collected weekly. All feed and fecal samples were dried in a forced-air oven (60°C) for 72 h and ground in a Wiley mill to pass a 1-mm screen and composited on a dry matter basis (Table 9).

Feed and fecal samples were analyzed for DM, OM, N and starch according to AOAC (2000) methods, and Ca, P, Zn, and Cu were determined using inductively coupled argon plasma methods (Fassel 1978). Acid detergent fiber and NDF were determined according to Van Soest et al., (1991). Chromium content of feces was determined using inductively coupled argon plasma methods (Fenton and Fenton, 1979). Measured intake and the estimated total fecal output were used to determine the total diet digestibility by the following equations; Fecal DM output (g/d) = Cr consumed (g/d) / Cr concentration in feces (g/g DM); DMD = DMI – FO / DMI x 100.

<u>Statistical Analysis</u>

Intake and digestibility were analyzed as a 2 x 2 factorial arrangement of treatments using the general linear model (GLM) procedure and LSD of SAS (SAS Inst. Inc., Cary, NC 2001). The main effects of age and processing method were determined along with the age x processing interaction. Animal was the experimental unit, and differences were considered significant at $P < 0.05$.

Table 9. Nutrient analysis of barley supplemented hay diet fed to cows and calves in experiment 1

Item	Hay	Barley	CP Supplement
DM Analysis			
Dry Matter, %	90.17	92.20	89.50
N, %	1.72	2.64	5.87
ADF, %	39.20	7.81	17.00
NDF, %	62.30	29.00	23.80
Starch, %	--	42.58	3.41
Calcium, %	0.92	0.14	5.38
Phosphorus, %	0.26	0.55	1.22
Zinc, ppm	22	43	1366
Copper, ppm	6	10	483
Test wt., $kg \cdot bu^{-1}$		19	

Experiments 2&3 – Effect of Animal Age, Gender and Barley Grain Processing Method on Performance and Diet Digestibilities of Beef Cattle

Experiment 2 - Performance Study

The objectives of these two experiments were to determine the effects of animal age (cows vs. calves) and barley processing method (whole vs. rolled), on rate and efficiency of gain and nutrient digestibilities when fed as a supplement to medium quality grass hay.

Forty, 36 mo old, pregnant (first trimester) Angus cows (488 ± 49 kg), twenty-one, heifer calves (98 ± 8 d of age; 107 ± 15 kg), and nineteen, steer calves (99 ± 7 d of age; 121 ± 16 kg) were used in this 63 d experiment. Treatments were arranged in a 2 x 2 + 1 (hay only) factorial arrangement testing the main effects of animal age (cows vs. calves), barley processing method (whole vs. rolled) and barley supplemented diets vs. a control (hay alone) diet along with the corresponding interactions on rate of gain. The dietary treatments consisted of light test weight barley (20.9 $kg \cdot bu^{-1}$), provided at 0.5% BW, grass hay, offered to cows at 1.8% of BW and to calves at 2.5% of BW. For the control diet, cows were fed grass hay at 2.5% of BW and to calves at 2.7% of BW. Rations containing barley were then formulated to be isocaloric (1.76 $Mcal \cdot kg^{-1}$ $NE_{m,}$ 0.97 $Mcal \cdot kg^{-1}$ NE_g; and all diets were formulated to be isonitrogenous (15% CP) by using a 31.6% commercially produced protein and mineral supplement. Cows received 0.9 $kg \cdot hd^{-1} \cdot d^{-1}$, while calves received 0.45 $kg \cdot hd^{-1} \cdot d^{-1}$. Nutrient profiles for the ingredients and are presented in Table 10.

A 10 d acclimation period was used to adapt animals to their pens, waters, and respective diets before the start of the experiment. All animals were fed at approximately 0700. Both cows and calves were randomly assigned to diets containing either whole barley, rolled barley or hay alone. All cattle were blocked by age and sex with pen as the experimental unit. Cows were placed in pens which contained five animals each. There were three replications for the whole and rolled barley supplements, while there were two replications for the hay-only treatment. Calves were allotted to 18 pens so that nine pens contained only steers and nine contained only heifers in order to compare any effects due to gender. Individual full weights were taken on two consecutive days at the beginning and end of the study and then averaged.

Experiment 3 - Digestibility Study

Upon completion of the 63 d growth trial, 12 cows, nine steers, and nine heifers were randomly selected and blocked by age for a 32 d digestion study. Animal was the experimental unit. Treatments were arranged in a 2 x 2 + 1 factorial arrangement of treatments testing the main effects of animal age (cows vs. calves) and barley processing method (whole vs. rolled), along with the corresponding interactions on diet and nutrient digestibility. The diet consisted of light test weight barley (20.9 $kg \cdot bu^{-1}$), medium quality grass hay (12.3% CP; 37.7% ADF, DM basis), and a 31.6% commercially produced protein and mineral supplement. Barley was provided at 0.4%, BW to cows and 0.3%, BW to calves, DM basis. Hay was provided to cows at 1.8%, BW and to calves at 2.0%, BW (DM basis), for the supplemented treatments (whole vs. rolled). For the hay only diet, cows received hay at 1.9%, BW and calves were fed at 2.6%, BW (DM basis). All cows received 0.9 kg·hd^{-1}·d^{-1}, of the CP supplement while all calves received 0.45 kg·hd^{-1}·d^{-1}. Supplemented and control diets were formulated to be isonitrogenous (15.0 % CP) and supplemented diets were formulated isocaloric (1.76 Mcal·kg^{-1} NE_m, 0.97 Mcal·kg^{-1} NE_g). A 10 d acclimation period was used to adapt animals to individual electronic feeding gates (Calan Gates, American Calan, Northwood, NH), and waterers'. Cows and calves were randomly assigned to treatments. Starting on d 1 and continuing through d 32, all animals were fed their respective diets at approximately 0700. Remaining orts on subsequent feeding days was weighed and composited to measure actual intake prior to feeding. Starting on d 21 and continuing through d 31, all animals were individually dosed with a gelatin capsule containing 10 g of chromic oxide to estimate fecal output. Fecal grab samples were collected from d 29 through d 32 at the time the chromic oxide was administered (1600 h). Feed and fecal samples were dried in a forced-air oven (60°C) for 72 h and ground in a Wiley mill to pass a 1-mm screen. Feed and fecal samples were analyzed for DM, OM, N and starch according to AOAC (2000) methods, and Ca, P, Zn, and Cu were determined using inductively coupled argon plasma methods (Fassel 1978). Acid detergent fiber and NDF were determined according to Van Soest et al., (1991). Chromium content of feces was determined using inductively coupled argon plasma methods (Fenton and Fenton, 1979).

<u>Calculations</u>

Measured intake and the estimated total fecal output were used to determine the total diet digestibility by the following equations:

Fecal DM output (g/d) = Cr consumed (g/d) / Cr concentration in feces (g/g DM); DMD = DMI – FO / DMI x 100.

Associative effects on forage DMD were estimated as the difference between the observed apparent total tract DMD and IVDMD for ground barley and the commercially produced supplement. In vitro DM digestibilities of the dietary ingredients were determined by the Tilley and Terry method described by Harris (1970); Table 10. In vitro DMD of the barley and supplement were then used to estimate forage fecal output DMD based on the estimated barley and supplement fecal output and digestibility of the total diet by the following equation:

FFO_{est} = TFO, g – BFO, g – SFO, g

FDMD = [(FDMI, g – FFO_{est}, g) / FDMI, g] x 100

Where FFO_{est} = estimated forage fecal output; TFO, g = total fecal output in grams estimated by Cr_2O_3 recovery; BFO, g = barley fecal output in grams; SFO, g = supplement fecal output in grams; FDMD = forage DMD; FDMI, g = forage DMI. The deviation between FDMD for supplemented and unsupplemented (control) diets was used as a measure of associative effects.

Statistical Analysis

All data were analyzed as a 2 x 2 + 1 factorial arrangement of treatments using the GLM and LSD procedures of SAS (SAS Inst. Inc., Cary, NC 2001). The main effects based on a weighted means of animal age, barley processing method along with the age x gender x processing interaction. Because there were no significant effects due to animal gender, this part of the statistical model was eliminated. Three separate models were analyzed for the performance, digestibility and IVDMD respecitvely. The models included supplement type (whole vs. rolled vs. hay only) x animal age (cow vs. calf). Each model was also analyzed as supplement (whole and rolled) vs. no supplement (hay only) x animal age (cow vs. calf). Differences were considered significant at $P < 0.05$.

Table 10. Nutrient composition of ingredients fed to cows and calves in experiments 2&3

Item	Hay	Barley	CP Supplement
Ration Comp.	---------------DM basis---------------		
Dry Matter, %	93.17	91.58	93.68
N, %	1.41	2.03	4.99
ADF, %	34.4	7.4	14.5
NDF, %	58.7	43.20	24.90
Starch, %	1.06	47.66	5.15
Calcium, %	0.32	0.07	4.84
Phosphorus, %	0.22	0.48	1.17
Zinc, ppm	15	30	1272
Copper, ppm	4	5	274
Test wt., $kg \cdot bu^{-1}$		20.9	
IVDMD, %[b]	47.02	88.17	83.24

Experiment 4 – Effect of Light Test Weight Barley vs. Wheat Midds on ADG and Carcass Characteristics in Calves Weaned at 75 d of Age

Objectives

The objectives were to determine the effects of feeding a higher starch (barley based) diet vs. a higher fiber (wheat midds based) diet on carcass characteristics of early weaned calves. This early weaning study was conducted at the E.L. Peterson Ranch in Judith Gap, Montana. Steer and heifer calves were born between February and April and nursed their dams while grazing native range. The calves were either early weaned (74 ± 16 d of age; n = 17) and adjusted to a high concentrate ration containing either 60% light test weight barley (17.25 $kg \cdot bu^{-1}$), or early weaned (73 ± 14 d of age; n = 18) and adjusted to a high concentrate ration containing 60% wheat middlings. Initially, forty-seven calves of similar genetics were weaned on May 29, 2002 from cows that were considered as culls by the ranch. Calves were randomly assigned to one of two treatments testing the effects of higher starch (light barley) vs. higher fiber (wheat middlings) diets on ADG, ultrasound measurements and carcass characteristics in early weaned calves. We allocated two pens per treatment with steers and heifers mixed within pen. There were two pens of barley-fed calves (pen 1; n = 9 steers, 3 heifers, pen 2; n = 8 steers, 3 heifers) and two pens of midds-fed calves (pen 1; n = 9 steers, 3 heifers, pen 2; n = 9 steers, 3 heifers). At the time of weaning all calves were weighed, and collected for s.c. and i.m. fat and longissimus muscle area at the 12^{th} rib using ultrasonography. All individual weights were full weights. Only steers were included in the overall analysis because heifer calves were retained as replacements.

Growing Phase

Calves were given ad libitum access to their respective diets (Table 11&12) and were fed at approximately 0700 h daily. Feed samples were collected every 7 d, dried in a forced-air oven (60°C) for 72 h, ground in a Wiley mill to pass a 1-mm screen and composited (DM basis). Feed samples were analyzed for DM and N according to AOAC (2000) methods, and Ca and P were determined using inductively coupled argon plasma methods (Fassel 1978).

Steer calves were implanted with Ralgro (36 mg zeranol) at approximately 50 d of age (branding) and again at approximately 155 d of age. At 155 d of age barley and midds-fed calves were vaccinated for protection against infectious bovine rhinotracheitis virus, parainfluenza-3 virus, *Haemophilus somnus*, *Pasteurella,* and Clostridia (Resvac 4/Somubac, One Shot, and Electroid 7 respectively; Pfizer, Schering-Plough) and dewormed with Cydectin pour-on (Fort Dodge). Ultrasound measurements were recorded at four time points at approximately 28 d intervals. Measurements were taken beginning with the day of weaning and then 34, 64, and 90 d post-weaning. Real time ultrasound measurements (RTU) were conducted using a Classic Medical Scanner 200 SLC veterinary ultrasound system (Classic Medical, Tequesta, FL) attached with an ASP-18 probe; 18 cm, 3.5-MHz. Digitized images were interpreted using Scanner 200 SLC (Classic Medical, Tequesta, FL) image analysis software. Subcutaneous fat thickness was measured at the 12^{th} to 13^{th} rib interface over the longissimus muscle. The perimeter of the longissimus muscle was traced from the digitized image and muscle area was computed by the software. Real time ultrasound images for s.c. and i.m. fat and longissimus muscle area were taken and interpreted by a single technician at all four time points.

Steers were shipped to a commercial feedyard (High Gain Feeders, Cozad, NE) 61 d following the end of data collection and were fed a finishing diet for 156 ± 5 d, Table 12. Steers were processed at a commercial packing plant (375 ± 5 d of age). Carcass data were collected 24 to 40 h postmortem by a USDA grader.

Statistical Analysis

Data were analyzed using the GLM procedures of SAS (SAS Inst. Inc., Cary, NC, 2001) for a completely randomized design. The model included effects due to diet, (light barley vs. wheat midds), birth date, weaning status, days on feed, harvest date, and yield grade. Effects due to time (performance from 75 d of age to 165 d of age), the weaning status x

time, longissimus muscle area x time, s.c. and i.m. fat x time interactions were analyzed using the MIXED procedures of SAS (Littell et al., 1998). Carcass marbling scores were calculated to estimate % of ether extractable fat (Savell et al., 1986). Differences in means were determined using the LSD procedures of SAS (SAS Inst, 2001). Animal was the experimental unit and differences were considered significant at $P < 0.05$.

Table 11. Ingredient and nutrient composition of growing diets fed to early-weaned calves

Item	Lt. Barley	Wheat Middlings
Ingredient, % DM basis		
Light Test Wt. Barley	57.7	--
Wheat Middlings	--	57.7
Barley Hay	15.4	15.4
Grass Hay	15.4	15.4
Canola Meal	3.8	3.8
Vitamin/Mineral Pellet[a]	7.7	7.7
Nutrient Analysis, DM basis		
CP, %	15.5	15.8
Ca, %	1.32	1.42
P, %	0.64	0.37
NE_m, $Mcal \cdot kg^{-1}$	1.83	1.78
NE_g, $Mca \cdot kg^{-1}$	1.19	1.17

[a]Nutrient specifications for the vitamin/mineral pellet; The nutritional program was to be a 1.82 kg/d weaning pellet (0.454 kg/d) fed for 28 d after weaning with the following minimum specifications; 16% CP, Crude fat 3%, Crude fiber 9%, Ca 0.8%, P 0.8%, Cu 80 ppm, Z 250 ppm, Mn 225 ppm, Se 1.65 ppm, DECCOX 31 mg/lb (62g/ton)

Table 12. Ration composition of the finishing diet (as fed) (High Gain feeders)

Ingredient	%, As fed
Flaked Corn	60.19
Alfalfa	7.29
Rolled Corn	12.26
Tallow	2.31
Liquid Supplement	6.32
Dry Supplement	1.50
Corn Steep	10.13

RESULTS AND DISCUSSION

Experiment 1 - Effect of Animal Age and Barley Grain Processing Method on Diet Digestibilities of Beef Cattle

No age x processing interactions were detected for OM, N, ADF or NDF digestibilities. Grams of OM, N, ADF, NDF, and starch intake were greater for cows compared to calves Table 13. Organic matter (52.8 vs. 43.3 %) and N digestibilities (39.2 vs. 27.2 %) were greater ($P < 0.01$) for calves compared to cows. Diet OM and N digestibilities were lower than apparent digestibilities reported by Mathison et al., (1991b). Their study fed barley of similar test weight to the light test weight barley used in the present study and included it at 33% of the total dietary intake. If negative associative effects on cell wall digestibility were to occur it would probably be when concentrate supplementation was provided between 0.4 and 0.6% of BW (Pordomingo et al., 1991). Caton and Dhuyvetter (1997) suggested that supplemental barley fed at 0.8% of BW would only marginally affect forage intake and digestibility of steers, which also concurs with work by Horn and McCollum (1987) who suggested that energy supplementation at 0.7% of BW would minimally affect forage utilization. Diets of these studies include grain supplementation at levels similar those fed in the present study, and Mathison et al., (1991b) likely saw greater apparent OM digestibilities than those in our study because DMD was increased due to higher levels of concentrate supplementation of forage diets (Ovenell et al., 1991). Numerous studies have also showed that higher fiber digestibilities along with lower starch digestion would be more favorable for increasing intake and total tract digestibilities (McDonnel et al., 1982; Klopfenstein et al., 1985; and Bernard et al., 1988), and a greater percent of starch may escape rumen degradation if fibrous roughages form part of the diet (Orskov 1986). However, differences in OM digestibility between ages were similar to results summarized by Mathison (1996) who compared cattle of various ages and weights. Their study reported that lighter weight cattle (≤370 kg, BW) digested more OM than cattle that weighed 390 kg or greater.Processing method likewise did not change OM, N, ADF or NDF digestibilities. These similarities in nutrient digestibilities disagree with results of Toland (1976) who reported a 62% improvement for rolled barley vs. whole barley grain fed to two year old Hereford steers.

A processing method x age interaction ($P < 0.05$) was measured for starch digestibility (Figure 3). Rolling the barley did not improve starch digestibility when fed to calves (avg. of 80.7%), but dry rolling did improve ($P < 0.05$) starch digestibility when fed to cows (71.4% vs. 23.3% for rolled vs. whole), and agrees with Mathison (1996) who found a 37% decrease in starch digestibility when whole barley was compared to rolled barley fed to two year old steers. Differences for whole vs. rolled barley are also similar to results of Toland (1976) who reported 49.4 vs. 98.8% starch digestibility, respectively. In the present study no differences were observed for starch digestibilities between cows and calves consuming rolled barley, but when whole barley was fed, starch digestibility was 68.4% lower when fed to cows compared to calves. These results are similar results of Shaw and Norton (1906) who determined that a greater amount of whole oats passed undigested through cows than calves. These results also confirm that younger cattle (calves) are more thorough masticators and ruminators than older cattle (Nicholson et al., 1971; Morgan and Campling, 1978), because similarities were found in starch digestion for whole barley vs. rolled barley supplements. Results of the present experiment agree with the reports by Morgan and Campling (1978) and Mathison (1996) who found that variation in starch digestibility was highest when whole barley was fed and lowest when the grain was processed. Unprocessed cereal grain must be masticated for rumen microbes to penetrate the pericarp and utilize available nutrients (Alberta Feedlot Management Guide, 2000). Cows may have masticated less than calves resulting in the lower starch digestibility observed for cows fed diets supplemented with whole barley grain. Beauchemin et al., (1994) observed mastication differences between different feeds; whole corn was found to be substantially damaged after ingestive mastication whereas many barley and wheat kernels remained intact. However, Kimberly (1976) found no differences in digestion of whole grain for cattle ranging from 6 to 24 mo of age. Calves and cows for the present study were approximately 7 and 31 mo of age, respectively. Younger cattle tended to digest a higher percent of starch in cereal grains than did older cattle (Kimberly 1976). Furthermore, Beauchemin et al., (1994) found that cattle fed whole barley spent twice as long ruminating per kg of DM as those fed corn. If whole grains are not physically damaged from mastication then digestion was severely depressed (Orskov et al., 1978; McAllister et al., 1990).

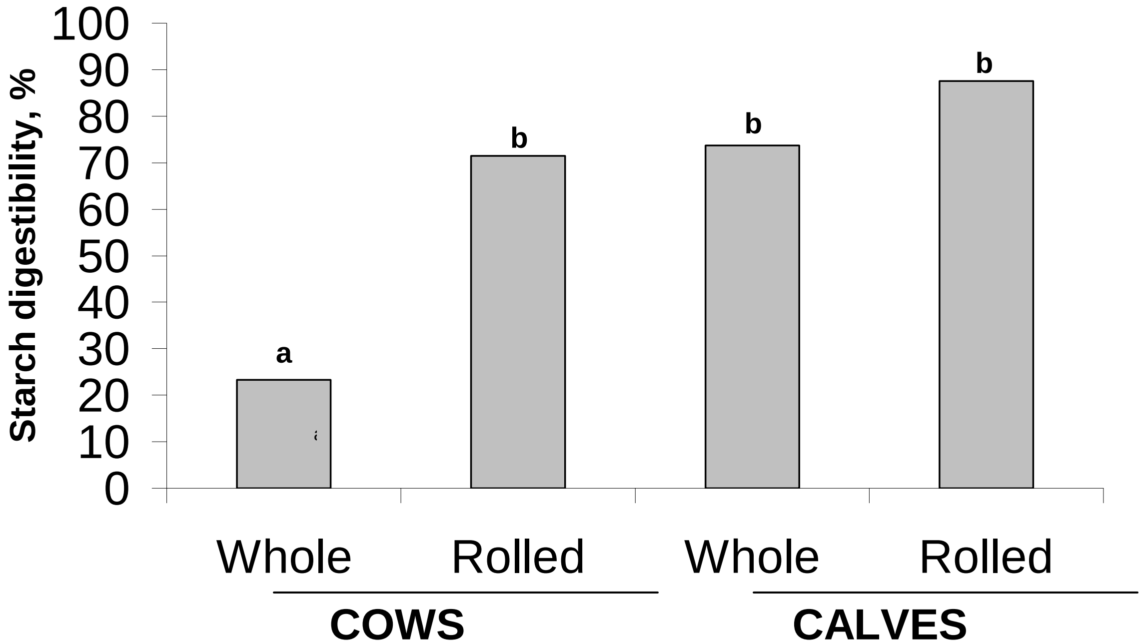
Three calves showed signs of acute bloat (2 whole vs. 1 rolled) during the acclimation period and one cow died (whole) due to bloat and was replaced 15 d prior to beginning the experiment. Upon necropsy, rumen pH for the cow was 4. Occurrence of bloat for the study was 12 % and the number of bloats for whole vs. rolled barley was the same (2 vs. 2). Mathison et al., (1991a) recorded twice as many bloats for whole barley as compared to rolled and attributed this difference to a longer rumen retention time for the whole barley. Based on observations by Shaw and Norton (1906) who reported a lower percentage of undigested oats being excreted in feces for calves vs. cows (3 vs. 12%), it could be speculated that calves have a greater ruminal retention time for cereal grain which could have led to the differences in the number of animals displaying physical signs of bloat.

Table 13. Effect of age and barley processing method on apparent total tract nutrient digestibility by cows and calves

Age:	**Cows**		**Calves**			***P* - value**	
Item, Processing:	Whole	Rolled	Whole	Rolled	SEM[a]	Animal Age[b]	Processing Method[c]
No. Animals	8	8	8	8			
Avg. BW, kg	535	530	245	244			
DMI, % BW							
Hay	1.5	1.5	2.07	2.08		0.01	NS
Barley	0.47	0.47	0.47	0.47		NS	NS
Suppl.	0.04	0.04	0.08	0.08		NS	NS
Total diet	1.99	2.01	2.62	2.64		0.01	NS
Intake ($g \cdot d^{-1}$)							
OM	9842	9842	5919	5919	--	0.01	NS
N	210	210	127	127	--	0.01	NS
ADF	3328	3328	2104	2104	--	0.01	NS
NDF	5697	5697	3529	3529	--	0.01	NS
Starch	1167	1167	540	540	--	0.01	NS
Digestibility, %							
OM	39.03	47.51	52.28	53.38	3.3	0.01	0.16
N	23.53	30.97	37.58	40.68	4.1	0.01	0.21
ADF	24.39	26.00	32.17	31.06	5.2	0.23	0.96
NDF	44.53	45.28	48.25	47.27	3.7	0.45	0.98
Starch[d]	23.33[e]	71.49[f]	73.74[f]	87.58[f]	7.2	--	--

[a]Standard error of least squares means
[b]Cows vs. calves
[c]Whole vs. rolled barley
[d]Age x processing interaction (within a row means without a common superscript letter differ $P < 0.05$)

Figure 3. Interaction of animal age and barley processing method on diet starch digestibility



[ab]Age x processing method interaction (means without a common superscript letter differ P < 0.05)

Experiments 2&3 – Effect of Animal Age, Gender and Barley Grain Processing Method on Performance and Diet Digestibilities of Beef Cattle

Experiment 2 - Performance Study

Rate and efficiency of gain are shown in Table 14. No interactions for age or processing method were found in this study. Somewhat surprisingly, animals fed the hay diet had a similar rate and efficiency of gain (P = 0.12) as the average of supplemented animals. This response does agree with results for BW change for control vs. grain supplemented diets for cows grazing native range (Kartchner 1980). Supplements (barley and CP supplement) comprised 24% of the diet fed to cows and calves. Owens (1986) suggested that when grain exceeded 20% of the diet that it became a substitute for forage rather than a supplement for forage. This may explain the lack of differences in performance for supplemented vs. unsupplemented diets. The control diet (hay only) was formulated to be isonitrogenous to barley supplemented diets and indicate that available N and microbial protein synthesis was of more importance in affecting animal performance than the equivalency in animal caloric intakes. Barley processing had no effect ($P = 0.12$) on rate or efficiency of gain for cows or calves. Results of our study differ from those of Mathison et al., (1991a), who found steers fed whole barley had reduced feed efficiency compared to those fed dry rolled barley. Owens et al., (1997) suggested that whole grain usually decreases performance compared to feeding processed grains, but also reported that steers in the feedlot fed whole vs. rolled barley did not differ in daily gain (1.38 vs. 1.45 $kg \cdot hd^{-1} \cdot d^{-1}$ respectively). Although the current study showed similarities in rate and efficiency of gains, the different dietary ingredients for a growing ration vs. a finishing ration suggests the importance of investigating associative effects between forage and concentrates for animals consuming high roughage diets.

Cows gained more weight than calves (65.2 kg vs. 34.4 kg), consumed more DM but were less efficient than calves (12.6 vs. avg. of 7.6; $P < 0.01$). Average daily gain was faster ($P < 0.01$) for cows (1.04 $kg \cdot hd^{-1} \cdot d^{-1}$) than calves (0.54 $kg \cdot hd^{-1} \cdot d^{-1}$). Average DMI's were similar for cows and calves when they were fed either the supplemented or unsupplemented diets. These results agree with those of Kartchner (1980) who found no differences in DMI for supplemented vs. unsupplemented diets in two studies using cows grazing native range. Increasing levels of grain in high roughage diets may cause a decrease in forage intake in grazing situations (Lusby and Wagner, 1986; Chase and Hibberd, 1987; and Pordomingo et al., 1991), however diets for the present study were fed at restricted levels of intake and no differences were observed in DMI for supplemented vs. unsupplemented diets due to the diets being completely consumed. Whole, rolled, and hay only diets for the present study were isonitrogenours (15% CP) and contained supplements at levels ≤ 0.7% of BW. Kartchner (1980) observed a decrease in forage DMI in one experiment and suggested that forage DMI be more negatively affected by roughage sources with greater protein content. The forage for the present study contained 8.81% CP. Addition of barley and the protein pellet likely improved microbial protein synthesis. Caton and Dhuyvetter (1997) suggested that supplemental barley fed at 0.8% of BW would only marginally affect forage intake and digestibility of steers, which also concurs with work by Horn and McCollum (1987) who suggested that energy supplementation at 0.7% of BW would minimally affect forage utilization. Cow and calf supplementation for diets in the present study were offered at 0.54 and 0.73 % of BW, respectively. These data suggest that improved performance was not measured when barley was supplemented or when it was processed. Orskov (1986) suggested less processing is more beneficial in terms of health, cost, and performance if the digestibilities among the treatments were similar.

Experiment 3 - Digestibility Study

No age x processing interactions were detected for OM, N, ADF, NDF, or starch digestibilities (Table 15). No differences were found for OM or N digestibilities ($P > 0.05$) between cows and calves fed either whole or rolled barley supplements. These results differ from Nicholson et al, (1971), Ahmed et al., (1973), and Morgan and Campling (1978) who found decreases in OM digestibility when whole barley made up 33% or more of the entire diet. Likewise, no differences were detected in digestibility of DM, ADF, or NDF when the main effects of cows vs. calves or whole vs. rolled barley supplements were compared. Ovenell et al., (1991) observed total diet DMD to be increased by supplementation of forage diets with a concentrate. Interactions among feeds most likely occur when grain supplementation is between 0.4% and 0.6% of BW (Pordomingo et al., 1991). However, higher or lower levels of supplementation as a % of BW will only marginally affect diet DMD (Horn and McCollum 1987; Pordomingo et al., 1991; Caton and Dhuyvetter, 1997). Results of the present experiment agree with these suggestions as no differences were detected for DMD. Unlike results from experiment one and those of Toland (1976) and Mathison (1996), no differences in starch digestibility were detected between cows vs. calves or more surprisingly between rolled vs. whole barley supplements. Cows in experiment 1 were younger (31 mo of age) than those used for experiments 2&3. Unmeasured biological differences may have attributed to differences seen in starch digestibility of diets fed to cows from the first to second year. The first experiment found a 68% decrease in starch digestibility for whole vs. rolled barley when fed to cows compared to calves. Likewise Toland (1976) and Mathison (1996) found decreases to be 100% and 37% respectively for whole vs. rolled barley diets fed to two year old steers. Unfortunately barley of similar test weight to that used in the first digestibility study was unavailable in year two for the performance and digestion studies. Digestibility differences between studies may have also been attributed to experiment two diets containing heavier test weight (19 vs. 21 $kg{\cdot}bu^{-1}$) barley than experiment one, which resulted in a greater starch content for the heavier test weight barley in experiment two (42.58 vs. 47.66%). As would be expected, differences were detected ($P > 0.05$) for the amount of starch digested from barley supplemented animals compared to animals fed hay only, and supplemental starch level was undetectable in unsupplemented calf diets.

In vitro DM digestibility of the hay agrees with the predicted in vivo DMD of the hay diet (47.0 vs. 48.9%, cows; Tables 10 & 15). Associative effects for forage DMD were calculated based upon IVDMD of the barley and CP supplement. There were no differences ($P > 0.05$) for predicted forage DM digestibility when the supplements were whole vs. rolled barley treatments or more surprisingly for supplemented vs. unsupplemented diets. Total supplementation (barley and CP supplement) was approximately 0.6% of BW and comprised 24% of the total diet fed to cows and calves. Negative associative effects based on supplementation level of 0.6% of BW are in agreement with those of Horn and McCollum (1987) who suggested that supplementation at approximately 0.7% of BW would only minimally affect forage utilization. Therefore the suggestion of substitution from these results may explain the lack of differences in digestibilities and performance for experiment two.

Substitution rates were calculated according to Fieser and Vanzant (2004; Table 16) as a secondary method of evaluation. No interactions were detected for substitution rates (change in forage intake per unit of supplement intake) or deviations between observed and predicted DMD. Processing of barley resulted in no differences ($P > 0.05$)

with regard to DMI, DDMI, substitution ratio or differences in predicted and observed DMD (dDMD). These results differ from those of Fieser and Vanzant (2004) who found that corn supplementation at 0.67% BW (OM basis) increased DOMI by over 20% compared to forage only diets. Forage was offered at 150% of ad libitum intake for their study. Differences for the present study are likely a result ad libitum intakes of approximately 100% of recommended levels (NRC, 1996). If barley addition to the diet was to stimulate forage DMI (FDMI) and subsequently forage OMI (FOMI), it was immeasurable. Thus, these differences in our study are likely a result of forage being fed at lower levels. Substitution ratios were only calculated for the performance study because the digestibility study included diets fed at restricted intakes.

Differences were detected ($P < 0.01$) between treatments (whole and rolled) vs. controls (hay without barley supplement) for substitution ratio (change in forage intake per unit of supplement intake) when accounting for the inclusion of both barley and the CP supplement. Control (hay only) diets did include the CP supplement and as a result the substitution ratio suggests that forage intake was 85% greater for cows receiving control diets vs. those including whole or rolled barley. Subsequently, had forage been offered at levels similar to Fieser and Vanzant (2004) as a result, calculated substitution ratios may have also been greater. Cows consuming the control diets were also offered a greater amount of forage than cows receiving diets containing barley supplement in order to meet total DMI requirements (NRC 1996). A 91.4% decrease in substitution ratio was detected in control vs. treatment diets for calves suggesting that the barley simply replaced the forage rather than stimulating a response for greater forage intake. An age effect also showed an 84% decrease in the substitution rate for the change in FDMI per unit of barley supplement for cows vs. calves. No differences were detected in substitution ratios between treatments (whole and rolled), and are in agreement with findings of Fieser and Vanzant (2004). Although individual nutrient digestibilities were similar ($P > 0.05$), differences between ages were detected for dDMD for predicted vs. observed calculations. Supplemented diets had much greater observed DMD than controls (hay only) and thus dDMD was higher ($P \leq 0.01$) for supplemented vs. unsupplemented diets as well as for calves compared to cows. This appears to have resulted from the greater DMI for animals receiving supplemented diets that included barley, and these calculations offer validity of calculated apparent total tract digestibilities, Tables 15&16.

Unfavorable rumen conditions from the addition of a rapidly fermentable carbohydrate may decrease fiber digestion (Fieser and Vanzant (2004). Digestible OM:CP (DOM:CP) ratios were calculated according to McCollum (2004) as an indirect measure of rumen equilibrium. McCollum (2004) suggested that rumen microbes require a DOM:CP ratio of about 4:1. Digestible OM:CP ratios are listed in Table 17. Forage DOM:CP ratios are similar to ratios suggested by McCollum (2004), 4.25 vs. 3.84 for supplemented vs. unsupplemented diets, respectively. Results of the present experiment suggest that ruminal balance was occurring and supports similarities observed for nutrient digestibilities for the whole and rolled barley and hay only diets. The lower DOM:CP ratio for the control (hay only) diet suggests that addition of the commercially produced protein supplement may be more beneficial to the rumen environment and thus would explain the greater forage intake found in calves fed unsupplemented diets. Barley has a higher protein value than corn (13 vs. 9% CP, respectively) and thus would be more favorable for DOM:CP ratios. In contrast cows fed unsupplemented diets had lower FDMI but this observation likely related to the limited amount of forage offered daily as the diet was fed at 90% of ad libitum intake according to 1996 NRC requirements. However, in grazing situations such an observation could be a result of protein levels exceeding the available energy supply (McCollum 2004).

Ahmed et al., (1973) observed greater depressions in fiber digestion for forage diets supplemented with rolled grain as opposed to whole grain, Mathison (1996) concluded that whole barley would be 10-30% less digestible than dry-rolled barley, with the proportion of forage in the diet having little influence on the digestibility of whole grain. Whole grain generally results in a lower diet digestibility than rolled grain supplementation and rolled grain suppresses fiber digestion to a greater extent than whole grain (Alberta Feedlot Management Guide, 2000). Because similar results were found for supplemented vs. control diets in experiment 2, Chapter 5 evaluates economic input costs for these experiments. The similar results for supplemented vs. control diets in experiment two reflect the importance of future research involving economic differences of feeding processed vs. unprocessed grains.

Table 14. Effect of animal age (cows vs. calves), barley processing method (whole vs. rolled) and supplementation (no barley vs. barley at 0.5% of BW) on rate and efficiency of gain

	Cows			**Calves**				**Main Effects *P* – value**		
Item:	Whole	Rolled	Hay Only	Whole	Rolled	Hay Only	MSE[a]	Animal Age[b]	Hay only vs. Supplemented	Processing Method[c]
No. Animals	15	15	10	13	13	14				
No. Pens	3	3	2	6	6	6	22.000	0.03	NS	NS
Initial BW, kg	499	512	455	106	112	124	188.455	0.01	0.02	NS
Final BW, kg	558	577	524	141	148	155	166.113	0.01	0.01	NS
Total gain,kg	59	65	69	35	36	31	0.035	0.01	NS	NS
ADG, $kg \cdot d^{-1}$	0.95	1.04	1.11	0.55	0.57	0.51	0.035	0.01	NS	NS
F:G	12.61	11.57	10.66	6.40	6.18	7.06	5.109	0.01	NS	NS
DMI, $kg \cdot d^{-1}$	11.98	12.03	11.83	3.52	3.52	3.60	0.000	0.01	NS	NS
DMI, % BW										
Hay	1.86	1.82	2.51	2.59	2.45	2.73	0.082	0.01	NS	NS
Barley	0.46	0.45	0.00	0.54	0.51	0.00	0.002	0.03	0.01	NS
Suppl.	0.08	0.08	0.09	0.19	0.18	0.17	0.0003	0.01	NS	NS
Total diet	2.40	2.35	2.60	3.32	3.14	2.9	0.082	0.01	NS	NS

[a]Mean Square Error

[b]Cows vs. calves

[c]Whole vs. rolled barley fed at 0.5% of BW

Table 15. Effect of animal age (cows vs. calves), barley processing method (whole vs. rolled) and supplementation (no barley vs. barley at 0.5% of BW) on apparent total tract nutrient digestibility

	Cows			**Calves**				**Main Effects *P* – value**		
Item:	Whole	Rolled	Hay Only	Whole	Rolled	Hay Only	MSE[a]	Animal Age[b]	Hay only vs. Supplemented	Processing Method[c]
No. animals	4	4	4	6	6	6				
Intake ($g \cdot d^{-1}$)										
OM	11850	11846	10038	3601	3798	3950	603572	0.01	0.01	NS
N	270	270	229	84	90	102	314.77	0.01	0.01	NS
ADF	4282	4280	4093	1312	1384	1602	98159	0.01	NS	NS
NDF	7206	7204	6500	2187	2306	2543	249828	0.01	NS	NS
Starch	1154	1153	134	353	372	52	671557	0.01	0.01	NS
Digestibility, %										
DM	59.29	61.92	48.89	60.82	59.22	60.26	106.94	NS	NS	NS
OM	62.77	65.53	52.40	63.93	62.73	62.77	98.59	NS	NS	NS
N	64.05	67.24	52.42	61.13	61.53	65.41	92.07	NS	NS	NS
ADF	53.71	52.59	39.35	55.02	49.98	53.13	133.35	NS	NS	NS
NDF	56.98	56.58	45.45	59.82	56.19	58.99	125.30	NS	NS	NS
Starch	84.49	78.82	28.08	73.76	80.91	ND[d]	3082.42	NS	--	NS
Forage	50.31	53.80	46.45	51.45	49.30	57.93	145.70	NS	NS	NS

[a]Mean Square Error
[b]Cows vs. calves
[c]Whole vs. rolled barley fed at 0.5% of BW
[d]Supplemental starch digestibility was undetectable

Table 16. Effects of barley and protein supplementation on dry matter intake (DMI), digestible DM intake (DDMI), substitution ratios, difference between predicted and observed DMD (dDMD)

Item :	Cows			Calves				Main Effects *P* – value		
	Whole	Rolled	Hay Only	Whole	Rolled	Hay Only	MSE[a]	Animal Age[b]	Hay only vs. Supp	Processing Method[c]
No. animals	4	4	4	6	6	6				
DMI, % BW										
Total	2.33	2.36	2.06	2.57	2.76	2.91	0.106	0.01	NS	NS
Hay	1.76	1.78	1.92	1.91	2.06	2.64	0.069	0.01	0.01	NS
Barley	0.42	0.43	--	0.30	0.32	--	0.002	0.01	--	NS
Supplement	0.15	0.15	0.14	0.25	0.27	0.27	0.001	0.01	NS	NS
Barley + Supp	0.57	0.58	0.14	0.55	0.59	0.27	0.004	0.07	0.01	NS
DDMI, % BW[a]	1.38	1.47	1.08	1.59	1.64	1.75	0.123	0.01	NS	NS
Substitution rate[b]										
Barley	-0.39	-0.38	--	-2.72	-2.00	--	1.44	0.01	--	NS
Barley + Supplement	-0.29	-0.28	-0.53	-1.47	-1.08	-0.11	1.90	0.32	0.01	NS
DMDpred[c]	1.10	1.18	1.02	1.20	1.20	1.61	0.411	0.047	0.49	NS
DMDobs[c]	1.38	1.47	1.08	1.59	1.64	1.75	0.123	0.01	0.23	NS
dDMD[d]	-0.28	-0.29	-0.06	-0.39	-0.44	-0.15	0.004	0.01	0.01	NS

[a]Digestible dry matter intake
[b]Change in forage intake per unit of supplement intake
[c]Predicted and observed DMD
[d]Differences between predicted and observed DMD

Table 17. Differences in forage and supplement digestible OM:CP (DOM:CP) ratio for cows and calves fed the treatment diets (whole/rolled barley + CP supplement) or control diet (hay + CP supplement)

	Medium quality grass hay	
Item:	Supplemented diet (barley & CP)	Control diet (hay + CP supplement)
Forage crude protein, %	8.81	8.81
Forage TDN, %[a]	62.9	62.9
Supp CP, %	25.5	31.2
Supplement TDN, %[a]	74.4	62.1
Diet crude protein, %	15	15
Diet TDN, %[a]	63.74	57.59
Forage DOM:CP[b]	7.14	7.14
Supp DOM:CP[b]	2.92	1.99
Diet DOM:CP[b]	4.25	3.84

[ab]Calculated according to McCollum (2004)

Experiment 3 – Effect of Light Barley vs. Wheat Midds on ADG and Carcass Characteristics in Calves Weaned at 75 d of Age

There was no morbidity or mortality from the time of weaning until the calves were sent to the commercial feedlot. There were no differences in initial body weights, daily gains from birth to weaning, longissimus muscle area, or s.c. or i.m. fat ($P > 0.05$).

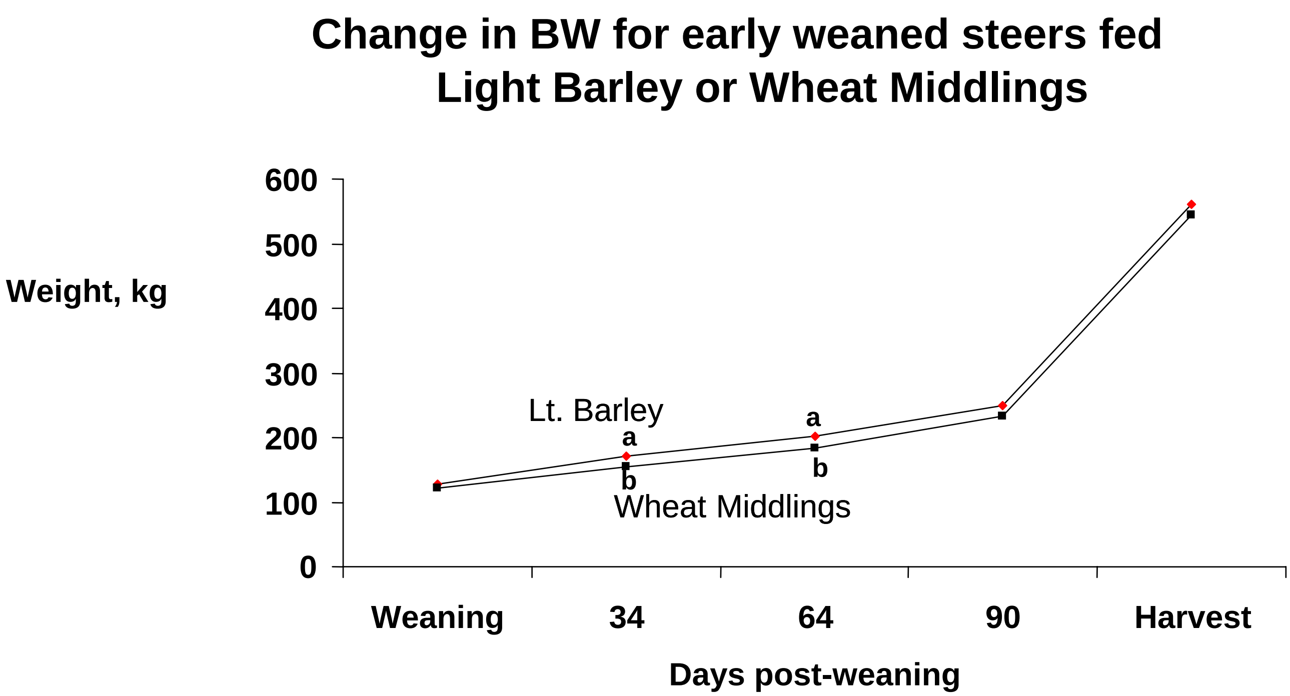
During the first period 34 d barley calves achieved higher weight gain and marbling scores (4.44 vs. 3.31 %EEF; $P = 0.002$) compared to midds-fed calves, Table 18. These results agree with Prior (1983) who suggested that higher starch diets for cattle will increase marbling score compared to forage based diets. Our observations also agree with Cianzio et al., (1982) who found that lower s.c. fat does not necessarily predict reduced marbling scores, and that both hypertrophy and hyperplasia may be occurring post-weaning (Cianzio et al., 1985). As marbling score increased over the first 34 d, s.c. fat remained similar for barley vs. midds-fed calves (0.15 vs. 0.15 cm, $P = 0.89$). After 64 d post-weaning barley-fed calves exhibited a significantly greater amount of s.c. fat compared to midds-fed calves (0.51 vs. 0.15 cm, $P < 0.01$), with no differences being detected at 90 d post weaning or at harvest. Although statistical differences were not measured for s.c. fat throughout other periods of the feeding phase or i.m. fat at harvest, numerical differences did occur. Interestingly, it appeared that barley-fed calves required increasing levels of energy as suggested by the initial increase in i.m. fat with no increase in the calculated estimate, % EEF beyond 34 d post-weaning. This speculation in supported by Fluharty et al., (2000) as carcass fat percentage was numerically greater for early-weaned calves fed 90 and 100% concentrate diets vs. those fed 60% concentrate diets. Although no differences existed between dietary treatments in the present study, calculated final yield grades were similar to those reported by Fluharty, et al., (2000) for early-weaned calves fed 60% concentrate diets (3.32 vs. 3.5).

Barley calves gained faster (1.29 $kg \cdot d^{-1}$ vs. 0.99 $kg \cdot d^{-1}$; $P = 0.002$) during the first period and consequently BW 34 d and 64 d post-weaning were significantly greater ($P = 0.04$) and were numerically greater ($P = 0.08$) until 90 d post weaning as barley-fed calves were heavier at all three time points (34 d = 171 kg vs. 154 kg; 64 d = 203 kg vs. 184 kg; 90 d = 250 kg vs. 233 kg; Figure 4).

Gains for the entire 90 d growing period gains were significant (barley = 1.36 $kg \cdot d^{-1}$ vs. midds = 1.24 $kg \cdot d^{-1}$; $P = 0.045$). The barley-fed calves did deposit more i.m.

fat from the time of weaning until 34 d post-weaning and retained this until transported to the finishing lot (4.44 vs. 3.31; % ether extractable fat). Calculated final live weights were only numerically greater for barley-fed calves compared to midds-fed calves. However, by time of harvest, midds-fed calves caught up and differences were nonsignificant (Figure 5). Dalke et al., (1997) suggested that wheat middlings could only replace up to 5% of dry rolled corn in high concentrate diets. However, Brandt et al., (1986) reported no reduction in the rate and efficiency of gain for finishing diets of steers when pelleted wheat middlings replaced approximately 10% of dry rolled corn. Results of the present study suggest that wheat middlings are a suitable substitute for light test weight barley in diets for early-weaned calves. The midds-fed calves appeared to have exhibited compensatory gain following an extended backgrounding period (151 d, first 90 d measured), thus these data imply that wheat middlings were as effective as light test weight barley in terms of providing similar performance. Nutrient content variability for barley (Bowman, 2001) and wheat middlings (Dalke et al., 1997) indicate the importance of comparing cost$\cdot$kg^{-1} gain in production systems.

Figure 4.



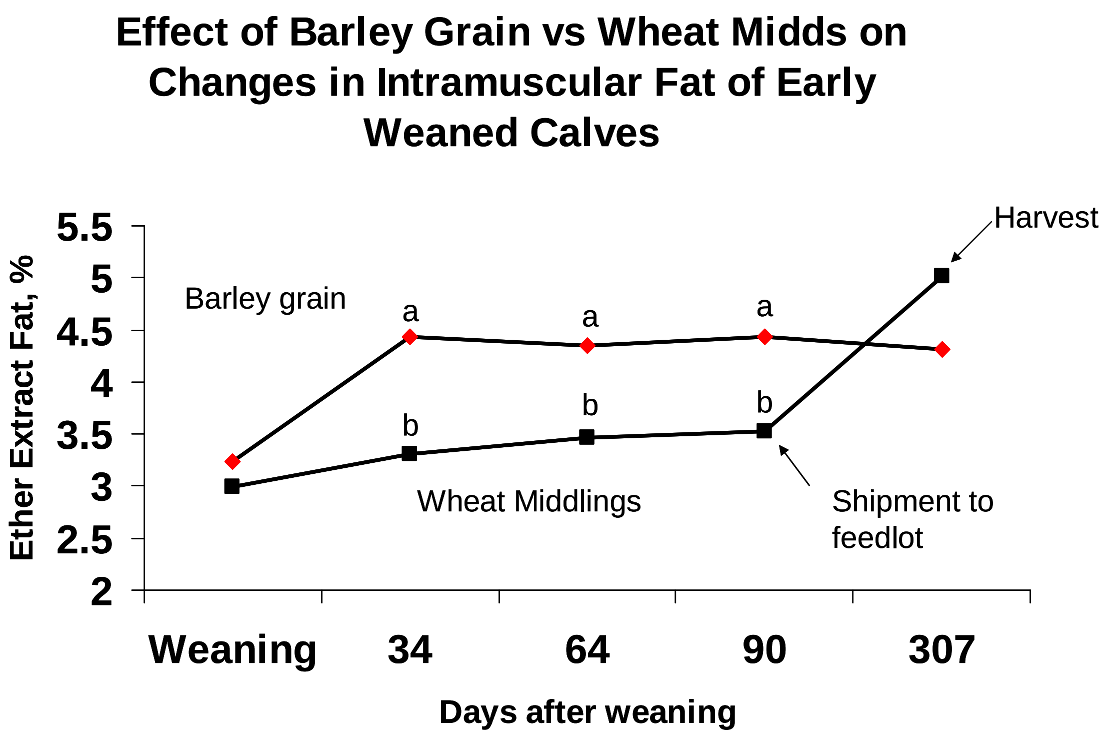
[ab]Differences in body weight post-weaning ($P < 0.05$)

Table 18. Subcutaneous, intramuscular fat% and ADG for calves in experiment 4

Item:	Barley	Midds	SE[a]	*P*-value[b]
Subcutaneous fat, %				
0-34	.15	.15	0.115	0.98
0-64	.51	.15	0.115	0.01
0-90	.24	.21	0.115	0.79
0-harvest	1.34	1.45	0.133	0.43
Intramuscular fat, %				
0-34	4.44	3.31	0.33	0.01
0-64	4.35	3.47	0.33	0.01
0-90	4.44	3.53	0.33	0.01
0-harvest	4.31	5.01	0.38	0.07
ADG, kg	1.36	1.24	0.09	0.045

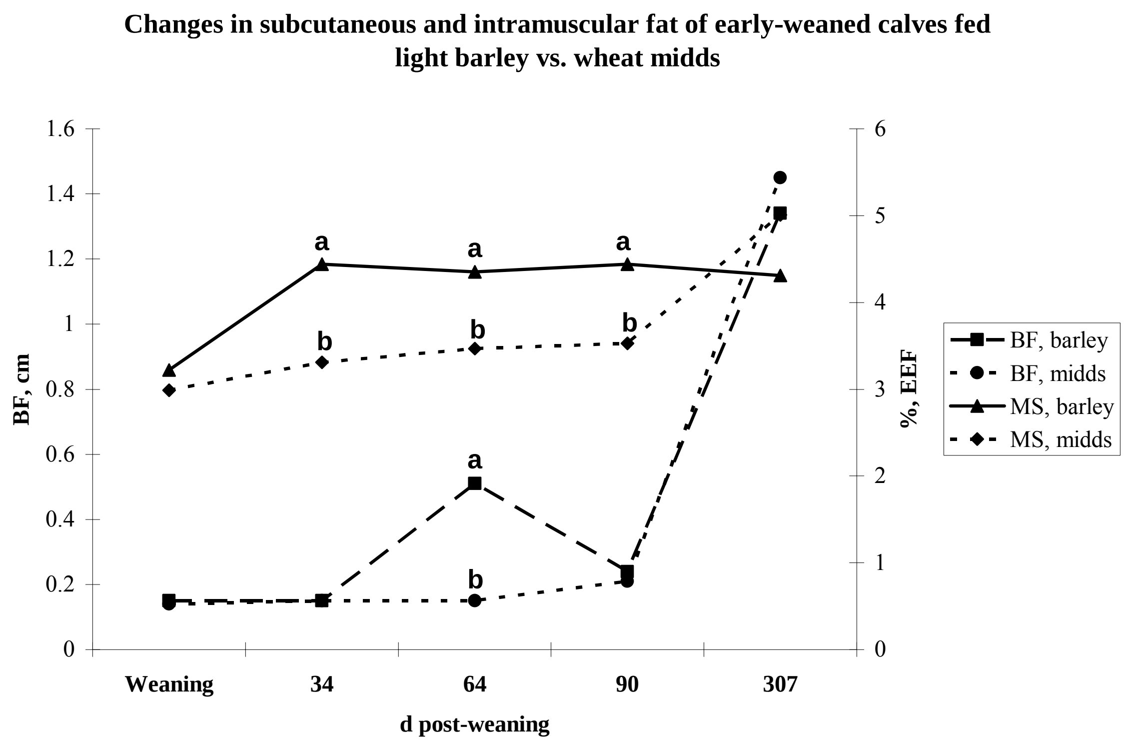
[a]Standard error of the mean
[b]Differences signicant ($P < 0.05$)

Figure 5



[ab]Means without a common superscript letter differ (*P* < 0.05)

Figure 6.



abDifferences significant $P < 0.05$

Cost Analysis

Economic comparisons of feed grains may vary on an annual basis due to fluctuation in price that may be directly affected by supply and demand and indirectly by a multitude of other factors, which may include yardage costs. Input cost analysis was based upon actual purchase pricing for the three experiments. The digestibility study in year one had purchase prices of $85 per ton for hay, $60 per ton for whole barley, and $180 per ton for the commercially produced supplement. A $15 per ton processing fee was added for treatments in all experiments that included rolled barley (Tables 19, 20 & 21).

Table 19. Ration ingredient cost ($/hd/d) and cost/kg gain for experiment 1

Item:	Cows		Calves	
	Whole	Rolled	Whole	Rolled
	----------------$/hd/d----------------			
Hay	0.80	0.80	0.51	0.51
Barley	0.18	0.23	0.08	0.10
Supplement	0.04	0.04	0.04	0.04
Total, $/d	1.03	1.07	0.64	0.66

The performance and digestibility studies conducted in year two had similar pricing analysis for all feed ingredients except for the hay, Table 20. Due to ongoing drought in the Northwest differences in the price/ton of hay were evident. In year one grass hay (10.8% CP; 39.2% ADF) was purchased for $85/ton. With less supply and increased demand we saw prices for available forage increase to $102/ton (grass hay; 8.81% CP; 34.4% ADF) in year two. Unlike the differences seen in hay pricing, cost of barley for these experiments were the same $60/ton, although nutritive value and test weight was higher in year two (47.66%, 19 vs. 42.58% starch, 20.9 kg/bu) compared to year one. Likewise base value for higher quality, heavier test weight barley (Montana Wheat and Barley Committee 1999) was not assessed. Generally, a 1% discount is endured for every kg below normal test weight (21.8 kg/bu; Alberta Feedlot Management Guide 2000). A $15 processing fee was also added for dietary treatments that included rolled barley in experiments two and three.

Table 20. Ration ingredient cost ($/hd/d) and cost/kg,gain for experiment 2

Item:	**Cows**			**Calves**		
	Whole	Rolled	Hay	Whole	Rolled	Hay
	-------------------------$/hd/d--------------------------					
Hay	1.22	1.22	1.53	0.36	0.36	0.46
Barley	0.18	0.22	--	0.05	0.06	--
Supplement	0.09	0.09	0.09	0.04	0.04	0.04
Total	1.49	1.54	1.62	0.45	0.46	0.50
ADG, kg/d	0.95	1.04	1.11	0.55	0.57	0.51
Cost/kg gain	1.57	1.48	1.46	0.82	0.81	0.98

Although cows showed no significant differences for ADG or starch digestibility across treatments, cost/kg of gain was highest for cows fed whole barley, and lowest for those receiving diets containing no barley supplementation. As would be expected cost/kg of gain was lower for the calves compared to the cows, due to their much lower DMI. Comparisons with age showed monetary differences in terms of cost/kg of gain. Unlike differences seen in the cows, calves that received supplemental barley diets at 0.5% of BW had lower costs of gain than unsupplemented diets. Although barley processing was an additional $15/ton for these studies, cost/kg of gain was actually lower when the barley was rolled. Because no differences were detected for animal performance or diet digestibility cost evaluation should be conducted on a situational basis. Previous research that found greater differences in performance and diet digestibility (Toland, 1976; Morgan and Campling, 1978; Mathison, 1996) may have seen even greater differences in cost of gain.

Ingredients for diets in the early-weaning study were ranch raised with the exception of the canola meal and the pelleted supplement (Table 21). Actual cost/ton for dietary ingredients was as follow: Grass Hay \$80/ton; Barley Hay \$60/ton; Canola Meal \$240/ton, CP supplement \$180/ton; Light Barley \$60/ton; Wheat Middlings \$65/ton. An additional \$15/ton was again included for the processing cost of the light test weight barley since cattle receiving light test weight barley received it in the rolled form.

Table 21. Ration ingredient cost (\$/hd/d) and cost/kg,gain for experiment 4

Item:	**Light Barley**	**Wheat Middlings**
	----------\$/hd/d----------	
Grass Hay	0.08	0.08
Barley Hay	0.06	0.06
Lt. Barley	0.28	--
Wheat Midds	--	0.24
Canola Meal	0.05	0.05
Supplement	0.04	0.04
Total	0.52	0.48
ADG, kg/d	1.36	1.24
Cost/kg gain	0.38	0.39

Cost per unit of gain was similar between treatments but remained \$0.01 lower for the calves fed rolled light test weight barley. Early-weaned calves fed 60% concentrate diets that included light test weight barley did gain at a faster rate ($P < 0.05$) over the entire 90 d growing period (1.36 vs. 1.24 kg/d) compared to wheat midds-fed calves. The

$0.01 difference in cost/kg of gain suggest that it was more economical to provide calves with diets that included light test weight barley rather than wheat midds. Availability of feed ingredients (lt. barley and wheat midds) was of little concern for this experiment.

Previous research has evaluated differences in processing methods for barley (Mathison, 1996). Different processing methods of cereal grain may have higher or lower processing costs. Our experiments only included dry rolled barley because dry rolling is the most commonly accepted method for processing of feed grains fed to cattle. Dry rolling allows for a lower incidence of metabolic disorders and little benefit is gained in animal performace for feed grains processed beyond dry rolling (Alberta Feedlot Management Guide 2000).

SUMMARY AND CONCLUSIONS

Experiment 1 - Effect of Animal Age and Barley Grain Processing Method on Diet Digestibilities of Beef Cattle

Results of this study suggest that there was no advantage in processing light test weight barley when fed as a supplement for medium quality grass hay to calves. However, these data suggest that processing barley was required for mature cows because of depressed starch digestibility compared to whole barley. The cause of this variation in starch digestibility was probably related to differences in mastication and rumination (Shaw and Norton 1906; Nicholson et al., 1971; Morgan and Campling 1978). These results provide additional evidence that the effects of barley processing on forage digestion could influence animal performance.

Experiments 2&3 – Effect of Animal Age, Gender and Barley Grain Processing Method on Performance and Diet Digestibilities of Beef Cattle

Results of these experiments imply that animal performance and nutrient digestibilities were not improved when barley was supplemented to hay diets at 0.5% of BW. Processing did not improve performance compared to feeding whole barley. Calves gained more efficiently than cows. Despite the lack of equal caloric value, animals consuming control diets (hay only) had similar rate and efficiencies of gain and diet digestibilities as supplemented animals. Cost of gain was cheaper for cows fed rolled barley. Likewise, barley supplementation for growing cattle diets (calves) was more economical for cost per unit of gain. Factors other than supplementation of barley appear to have affected diet digestibility and subsequent performance. Further research is warranted to better evaluate the need for processing light test weight barley in supplementation diets and decrease the variable responses seen in these studies.

Experiment 4 – Effect of Light Test Weight Barley vs. Wheat Midds on ADG and Carcass Characteristics in Calves Weaned at 75 d of Age

These data do not explain why barley calves initially deposited a greater amount of i.m. fat even though diets had similar NE content, yet harvested with similar quality grades as midds calves. It would appear tht in order to optimize the advantages of early-weaning, calves should be fed increasing amounts of energy in order to maximize rates and efficiencies of gain, attain higher quality grades and be harvested at a younger age. Despite similarities in final weights and carcass characteristics numerical differences in weight gain, carcass traits, and growth curves suggest that further research be focused on feeding regimens to determine if diet manipulation early in the growth curve can positively enhance carcass composition.

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