A Nutritional Guide to Feeding Pacific Northwest Barley to Ruminants

Richard C. Bull, Editor

College of Agriculture
University of Idaho

EXP 776

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Editor—Richard C. Bull, ruminant nutritionist, Department of Animal and Veterinary Science, University of Idaho, Moscow.

Authors—Lee Bradshaw, consulting nutritionist, Caldwell, and Carl Hunt, beef nutritionist, Department of Animal and Veterinary Science, University of Idaho, Moscow.

This publication was made possible by the generous support of the Idaho Barley Commission, the Oregon Grains Commission, and the Washington Barley Commission.

Published in 1995.

Sponsored by the PNW Barley Research Commission, 1200 NW Front Avenue, Suite 520, Portland, OR 97209-2800 TEL (503) 229-6574.

Published and distributed by the
Idaho Agricultural Experiment Station
Richard C. Heimsch, Interim Director
University of Idaho College of Agriculture
Moscow, Idaho 83844-2337

1,200 March 1995 Printed by Ag Communications Center $2.00

Barley: General Consideration

Richard C. Bull and Lee Bradshaw
Department of Animal and Veterinary Science
University of Idaho

Northwestern and other cool climate areas in the United States and Canada produce barley for human and livestock consumption. Barley is highly competitive with other agronomic crops in yield and market value in these cooler climates. Therefore, barley production has increased in importance in these regions as a crop for farmers to help manage their rotational cropping system.

Barley varieties, like other cereal grains, have been developed by plant breeders for their climatic conditions, thus yielding barley of high economic and feeding or malting value. Barley accounts for about 5% of the feed grains or 3% of the concentrates consumed by U.S. livestock (Ash 1992). In the Pacific and mountain regions, barley is the base feed grain for cattle and sheep diets in feedlot operations. Barley in these rations has about 95% (pound for pound) of the energy content of corn. However, its protein content (approximately 11%) is considerably higher than corn which can result in a substantial savings in protein supplementation costs in feedlot diets for cattle and sheep. Swine and poultry operations usually do not include barley in their rations because of its lower energy/higher fiber content (5-6%). This higher fiber content of barley may be an advantage to the lactating dairy cow to help maintain milk fat levels and rumen function by providing high energy diets with the adequate fiber levels necessary for high milk production.

Malting barley is the most valued variety of barley. However, growing conditions for malting barley may result in a substandard quality that is unsuitable for use by the malting industry. This grain can be marketed as livestock feed. Such malting barley may have a less plump kernel, resulting in less starch and higher protein content than the high value malting barley used by the malting industry.

Characteristics of Feed Grade Barley

Feed grade barley is normally sold on a test weight basis and the associated visual appraisal. Each grade of barley is characterized by its skinned and/or broken kernels, damaged kernels, foreign materials (wild oats, chaff, and other foreign material), test weight (weight/volume), barley variety, and black barley content (Wilson 1985). There are minimum and maximum limits established for each grade. Nutrient composition should be an integral part of the evaluation process for barley, but it is not currently used in the grading system. Differences in nutrient content may affect the feeding value of barley for non-ruminant animals, but are probably of lesser importance for ruminant animals.

Barleys from different sources are very diverse in their composition, especially in their protein and energy levels. There are varietal, geographical, and annual differences in composition. This has created some difficulties for nutritionists in formulating diets for livestock,

Table 1. Mean nutrient content (dry matter basis) of western grown barleys in 1983.[a]

	Type of Barley									
	2-Row[b]		6-Row[c]		Feed		Malting		Overall	
Nutrient	N	%	N	%	N	%	N	%	N	%
Crude Protein	22	12.400	24	12.100	12	10.900	34	12.800	46	12.300
Lysine	22	.460	23	.440	11	.420	34	.460	45	.450
Threonine	22	.410	23	.410	11	.390	34	.410	45	.410
Methionine	22	.240	23	.220	11	.210	34	.230	45	.230
Cystine/2	22	.220	23	.200	11	.190	34	.220	45	.210
Isoleucine	22	.370	23	.370	11	.360	34	.370	45	.370
Histidine	22	.410	23	.380	11	.360	34	.400	45	.390
Arginine	22	.720	23	.700	11	.660	34	.720	45	.710
Serine	22	.550	23	.540	11	.500	34	.560	45	.540
Proline	22	1.470	23	1.500	11	1.330	34	1.540	45	1.490
Fat	23	2.460	26	2.270	13	2.330	36	2.370	49	2.360
Starch	23	53.900	26	52.400	13	52.800	36	53.200	49	53.100
ß-glucan	14	5.300	15	5.600	11	5.500	18	5.500	29	5.500
ADF	22	5.800	24	7.300	12	7.800	34	6.200	46	6.600
Magnesium	22	.178	24	.169	12	.165	34	.177	46	.174
Calcium	22	.061	24	.068	12	.063	34	.065	46	.065
Phosphorus	22	.415	24	.390	12	.371	34	.413	46	.402
Non-Phytate P	22	.203	24	.194	12	.175	34	.207	46	.198
Phytic Acid P	22	.760	24	.700	12	.700	34	.730	46	.720

[a]Froseth et al. 1985.
[b]2-row varieties include: Andre, ANT 513 & 517 (western bred), Clark, Hector, Klages, Moravian III, Piroline, Bowman, and Summit.
[c]6-row varieties include: Advance, ANT 504, 525, & 531, Azure, Hazen, Karla, Morex, Robust, Briggs, Cm-72, Kobvar, Prato, Steptoe, and WB 501.

especially when source and variety are not known to the nutritionist.

A regional study was initiated in the 1980s to evaluate differences in nutritional value of 25 barley varieties grown in six northwestern states. These varieties consisted of eight 2-row malting, two 2-row feed, nine 6-row malting, and six 6-row feed types. Froseth et al. (1985) reported the mean crude protein (CP) was 12.3% with a range of 9.5 to 15.6% (Table 1). The essential amino acids, of lysine, threonine, methionine and cystine/2, have means and ranges of .45% (.33 to .59), .41% (.29 to .56), .23% (.13 to .36), and .21% (.12 to .37), respectively. Acid detergent fiber (ADF), starch, and ß-glucan concentrations (mean and range) were 6.6% (4.1 to 10.1), 53.1% (47.3 to 56.9),and 5.5% (4.2 to 6.7), respectively. Mean concentrations of Mg, Ca, total P, and non-phytate P were .174%, .065%, .402% and .198%, respectively. Two-row barleys were higher than 6-row barleys in fat, starch, and phytic acid content and lower in Ca, ADF, and ß-glucans. Malting types were higher than feed types in crude protein, serine, proline, cystine, arginine, lysine, P, non-phytate P, and Mg, but lower in ADF and kernel weight.

Geographical conditions may affect barley composition, including the percentage of crude protein and its lysine and methionine content; starch and ADF content; the percentage of plump kernels; fat; and the minerals of calcium, phosphorus (phytic and non-phytic acid), and magnesium. Therefore, the composition of western grown barley may have substantial variation in nutrient composition. Chemical analysis should be conducted on properly sampled barley sources before feeding. Proper formulation of diets allows the nutritionist to use the nutrient content of barley to the best advantage of the livestock production unit.

Characteristics of the Barley Kernel

The barley kernel can be subdivided into three basic parts: hull, endosperm, and germ (embryo). The hull portion, composed of the lemma and palea, contains most of the fiber. The hull-less cultivars, where the hull is easily removed during threshing, have relatively low fiber content as compared with hulled cultivars.

Hulls accounts for 7 to 17% of the kernel weight (Bhatty et al. 1975). Therefore, a reduction in the percent composition of the hull results in a higher percentage of endosperm and germ. These components contain more available energy because they are rich in starch and protein.

Barley endosperm, which is rich in starch, consists of several layers of tissue: aleurone, starchy endosperm, and depleted cell layer. Seven to 13% of the kernel weight is in the aleurone layer. It contains 60 to 85% arabinoxylan, up to 20% ß-glucans, 8% cellulose, and 6 to 16% protein (Newman and McGuire 1985). Starchy endosperm consists of starch granules of varying sizes and shapes. Approximately 63 to 65% of kernel starch is contained in the starchy endosperm layer. Non-waxy starch cultivars normally contain 75 to 85% amylopectin and 15 to 25% amylose (Ulrich et al. 1986). On the other hand, waxy starch cultivars consist of 97 to 100% amylopectin because of a mutation on chromosome 1 (Goering and Eslick 1976). As the starch content increases, the protein level of the barley grain inversely decreases. Depleted cell layer contributes little or no nutritional value to the animal's diet.

The germ content only makes up to 3% of the kernel weight, but it contributes to the total nitrogen (N) content of barley. Nitrogen from the aleurone layer and germ contribute about 30% of the total barley nitrogen content. However, barley protein content is highly variable, ranging from 9.1 to 24.1% of the barley kernel weight.

Barley Processing and Its Effect on Utilization by Animals

Processing methods for barley and other grains have been investigated to determine whether they will enhance nutritional value for poultry and livestock. The benefit of such processing depends upon the animal species and production level. Sheep are an example of the vast diversity in the impact of different process barleys on animal benefit. In a study of pregnant ewes with whole, rolled, or ground wheat or barley, Chestnutt (1992) reported no effect of cereal processing on organic matter digestibility, although digestibility of fiber was higher with whole than with processed grain. Sheep masticate or chew whole grains to a much greater extent than most other ruminant animals. However, in this report they recovered 18% of the wheat and 20% of the barley intact in the feces of sheep fed unprocessed grain. Dry rolling barley can significantly reduce fecal-voided barley, but there are conflicting reports on its effect on sheep performance and dry matter digestibility. Vipond et al. (1980) reported increased dry matter digestibility with lambs while Fraser and Orskov (1974) and Orskov et al. (1974) indicated dry matter and nitrogen digestibilities were higher for whole barley treatments as compared with ground barley. Some of these differences may be due to larger quantities of dusty feed residues. This can influence feed consumption and cause separation of micro- and macronutrients in the concentrate mixture, resulting in nutrient deficiencies and poor performance (Economides 1987). Pelleting diets with processed barley would eliminate the effect of dustiness caused by processing barley. Pelleted diets will not necessarily increase lamb and calf performance over those fed whole barley (Orskov 1973), although calves did have higher feed utilization on the pelleted diet (Economides et al. 1990).

Particle size reduction has been shown to improve barley digestion in swine by increasing particle surface exposure to digestive enzymes. Goodband and Hines (1988) reported that "fine grinding has a greater potential for improving feed/gain with a high-fiber cereal grain such as barley than with either corn or grain sorghum." Fine grinding barley (635 µm) increased the rate of gain and feed efficiency compared with medium ground barley (medium, 768 µm). This may be more important in finishing pigs since young pigs chew their feed more thoroughly than do finishing pigs. In all cases feeding pigs ground or rolled barley increases efficiency over feeding them whole barley. Pelleting the complete diet greatly enhances feed consumption, prevents feed ingredient separation, and reduces inhalation of dust by the pig (Gill, et al. 1965).

Feeding Value vs. Test Weight

Variety and growing conditions will alter the density or test weight (weight per unit volume) of barley. This raises the question whether the test weight of barley would affect the performance of poultry and livestock. In a swine study (Crenshaw et al. 1987), heavy (63 kg/hl[kilogram/hectoliter]) and light (50 kg/hl) barleys were mixed to form five test weights for barley diets (63, 57, 53, and 50 kg/hl) . Pigs fed ground barley diets had a greater rate of gain, improved gain/feed ratio, and higher dressing percentage ($P < .05$) as the test weight increased. However, if the diets were pelleted, there was no effect of test weight on performance.

With ruminant animals the relationship between test weight and animal performance is not consistent. Hanke and Jordan (1963) fed whole or pelleted barley of three different bushel weights to lambs and reported faster gains and an increase in consumption from feeding heavyweight barley. This agrees with Hinman (1978) who reported steer daily gain increased as barley test weight increased. Also, the feed required per kilogram gain was highest for the cattle on the lightest weight (543 g/l) barley treatments. However, Grimson et al. (1987) evaluated high barley rations (85% barley) with barley weights of 47.8, 55.6, and 66.6 kg/hl. They found no differences due to test weight, dry matter intake, or daily gain in beef steers. Other studies have reported a “plateau effect” as test weights increased above 59 kg/hl, but at lighter test weights there was a reduction of organic matter digestibility (2%) resulting in 6% more feed per unit gain in steers than at heavier weights (Mathison et al. 1991).

Perhaps a better measure of barley nutritive value for ruminants would be its starch and fiber content, rather than its test weight. Hepton (1994) reported that starch and organic matter digestibility increased linearly as the supplemental starch content of the diet increased. Also, barley hull fiber varied in content and quality, affecting ruminal degradability. Correlation coefficients of *in situ* degradation with ADF and NDF were -.90 and -.91, respectively.

Barley Starch Type

Starch granules are stored polysaccharides encapsulated in a protein matrix inside the endosperm of cereal grains (Rooney and Pflugfelder 1986). Each species of cereal grain produces granules of characteristic size, shape, and properties. The structure and composition of cereal starches, and their interactions with proteins, play a major role in the digestibility and feeding value of grain for livestock. The digestibility of starch by ruminant animals is affected by plant species that differ in the extent of starch-protein interaction, the physical form of the granule, presence of inhibitors, and type of starch present (amylose-amylopectin content [Rooney and Pflugfelder, 1986]).

The starch content of most cereal grains is 70 to 80% (Rooney and Pflugfelder 1986). The means and ranges for starch concentrations in grain dry matter are as follows: Corn, 71.9%, (63.7 to 78.4%); sorghum, 70.2%, (60.4 to 76.6%); wheat, 63.8%, (54.2 to 71.1%); oats 44.7%, (34.4 to 70.0%); and barley, 64.6%, (52.2 to 71.7%) (Waldo, 1973). Starch is a glucan composed of two major types of molecules, amylose and amylopectin, which are held together by hydrogen bonding (Rooney and Pflugfelder 1986). The amylose component consists of 20 to 30% of the starch granule, and is entirely comprised of a linear polymer of α-1,4 linked D-glucose units. Amylopectin is a much larger, branched polymer, and is considered the most abundant type of starch comprising 70 to 80% of normal starches. The amylopectin is depicted as linear chains of α-1,4 linked D-glucose that has α-1,6 branch points every 20 to 25 glucose residues of the amylose chain.

Starch granules are pseudo-crystals which have both organized (crystalline) and non-organized (amorphous) areas. The crystalline or micellar region is primarily composed of amylopectin which is resistant to water entry and enzymatic attack, and responsible for birefringence of the granule (Rooney and Pflugfelder 1986). The amorphous region (gel phase) is rich in amylose and is less dense than the crystalline area. Water moves freely through the amorphous region and allows an amylase to attack the granule while hydrolysis of the crystalline region occurs more slowly. It is thought that amylose molecules orient themselves inside the amylopectin crystallites, causing an increase in intermolecular hydrogen bonding which limits both swelling and enzymatic hydrolysis. The apparent intensity of birefringence depends on the thickness, size, shape, molecular structure, and orientation of the granule. In general, a starch granule exhibiting birefringence is considered to be in the native state. These differences in starch granule structure affect both starch digestibility and the processing properties of grains.

Starch Hydrolysis

Complete hydrolysis of starch and amylopectin (with isomaltase cleaving amylopectin after the branching points) to glucose requires amylase to form maltose, which is then cleaved by maltase to glucose (Owens et al. 1988). Starch digested by ruminal microbes first dissolve or liquefy starch by an extracellular α-type amylase (French 1973). The α–amylase, which rapidly reduces the molecular size of starch, randomly hydrolyzes the 1,4 glucosidic bonds within starch molecules, generating maltose, and branched and linear dextrins (endo-amylase activity; Rooney and Pflugfelder 1986; French 1973).

Amyloglucosidase is also employed to hydrolyze starch to glucose. (Owens et al. 1988). Rumen microbes, such as bacteria and fungi, produce amyloglucosidase, which hydrolyzes starch to glucose directly (Owens et al. 1986a). Amyloglucosidase and ß-amylases attack terminal glucose residues to yield maltose and glucose, respectively (exo-amylase activity [Rooney and Pflugfelder 1986]). The free glucose can then be used as an energy source for the rumen microbial population or absorbed by the ruminant animal.

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Feeding Value of Barley Grain for Beef and Dairy Cattle

C. W. Hunt
Department of Animal and Veterinary Science
University of Idaho

Introduction

Barley is an important feed grain for ruminant livestock species in many areas of the United States and the world. In North America barley is fed to livestock in cooler climates where it can be grown more successfully than corn and other feed grains. Consequently, barley is a particularly important feed grain throughout Canada , the Pacific Northwest, and the northern United States. As with other feed grain ingredients, the nutritive value of barley lies primarily with its energy value while protein is of secondary importance. Because corn is the predominant feed grain in the world, much of this review will focus on energy and protein comparisons between barley and corn.

In most feeding applications for beef and dairy cattle, barley is used to increase the energy density of a ration. The positive relationship between dietary barley level in forage-based rations and animal response (digestion, growth, or lactation) has been quite firmly established (Raven 1972; Griffiths and Bath 1973; Davies et al. 1977; Aston and Taylor 1980; and Leventini et al. 1990). Although side-by-side comparisons of barley and other grains have been lacking, the animal response from barley supplementation is similar to what might be expected from other grains.

Energy and Protein Content

The energy and protein values for barley and corn as shown in various publications of the National Research Council (NRC) are found in Table 1. The variability in energy and protein content is particularly evident for barley. The

Table 1. Crude protein and energy values for barley and corn as reported by the National Research Council (U.S.).

	Nutrient[a]		
Item	CP	ME (Mcal/kg)	NE_l (Mcal/kg)
Barley			
Beef NRC[b]			
grain	13.5	3.04	
Pacific Coast	10.8	3.11	
Dairy NRC/NRC Feed Composition[c]			
grain	13.5	3.29	1.94
Pacific Coast	10.8	3.38	1.99
grain, light (46.3 kg/hl)	14.0	2.98	1.77
Corn			
Beef NRC			
grain, grade 2	10.1	3.25	
Dairy NRC/NRC Feed Composition			
grain	10.9	3.42	2.01
grain, cracked	10.0	3.12	1.84

[a]CP = crude protein, ME = metabolizable energy, and NE_l = net energy for lactation.
[b]NRC, 1984.
[c]NRC, 1989; NRC, 1982.

reported values suggest a negative relationship between crude protein and energy content, with protein content increasing as the energy value is reduced. This relationship exists because of the variability in the starch content of the grain. If the kernels are less plump, the starch content is low (and fiber content is high) and there is a commensurately higher protein content.

This variability of values exemplifies the difficulty encountered in evaluating the nutritive values of feed grains. For example, the reported metabolizable energy (ME) values for barley range from 2.98 to 3.38 megacalories per kilogram and the net energy for lactation (NE_l) from 1.77 to 1.94 megacalories per kilogram. This variation is caused by both the variety of barley and its growing location. Reynolds et al. (1992) collected more than 1,600 spring barley samples from throughout northwest U.S. and evaluated chemical composition and ruminal digestibility. Samples represented an extreme divergency in acid detergent fiber, protein, starch, and ruminal dry matter degradability with approximately equal divergency attributed to growing location and barley variety (Table 2).

Another complication in evaluating nutritive value is the inherent difficulty in quantifying exactly the amount of energy which actually becomes available for the animal. For example, Reynolds et al. (1992) found a rather low correlation between ruminal degradability (a measure of available energy) and any of the chemical constituents measured. Sources of variability in the protein and energy content of grains must be identified before they can be successfully formulated in beef and dairy cattle rations. In general, barley grain is more variable in energy and protein content than other grains, therefore it is especially critical to analyze barley used as livestock feed.

Factors Affecting Digestion and Metabolism of Barley

Several important compositional characteristics distinguish barley from corn and grain sorghum. Barley has a negative impact on digestibility because it has a higher fiber content and, consequently, a lower starch content than most other grains. Fibrous carbohydrates are commonly less digestible, therefore yield less available energy, than starch or alpha-linked carbohydrates. The endosperm of barley represents proportionately less of the total kernel weight than in other grains. Hence, barley kernels are less concentrated with starch than other grains. Waldo (1973) reported that the mean starch content of corn is 71.9% within a range of 63.7 to 78.4%, while barley had a mean starch content of 64.6% within a range of 52.2 to 71.7%. This difference is the primary reason that barley is assigned a lower energy content than corn (Table 1). Barley has a positive impact on ruminal digestibility because the starch contained within barley is much more degradable (digestible) in the rumen than corn

Table 2. Divergency in nutritive characteristics of barley associated with year, variety, and growing location.

Item		Nutritive Characteristic			
		ADF	CP	Starch	ISDMD[a]
1989					
Variety[b]	low average	5.9	9.3	49.6	47.0
	high average	9.1	16.2	60.5	59.9
Location[c]	low average	6.8	10.3	47.0	42.7
	high average	8.6	17.3	60.7	58.6
1990					
Variety[b]	low average	6.3	8.4	46.8	42.8
	high average	11.1	17.6	55.4	58.6
Location[c]	low average	6.9	9.6	45.3	28.9
	high average	10.6	27.7	55.3	66.1

[a]ADF = acid detergent fiber and ISDMD = *in situ* DM disapperance (18 h ruminal incubation).
[b]Values represent the varieties with the low and high values for each analysis as averaged across growing location.
[c]Values represent the growing locations with the low and high values for each analysis as averaged across variety.
Adapted from Reynolds et al. (1992).

and grain sorghum. Therefore, while the starch content of barley may be lower, the starch which is present is more extensively digested and more thoroughly utilized by the animal. The following section is a presentation of literature which identifies the importance of these factors in energy utilization by the ruminant animal.

Starch and Fiber Content. The measure of the nutritive value of barley has traditionally been test weight (kg/hl or lb/bu). Only recently have nutritionists attempted to identify more accurately the nutritive value of barley as some chemical entity, such as starch or fiber. The relationship between test weight and the starch or fiber content of barley certainly exists, but it is far from a perfect relationship. As the kernel begins to "fill," starch is packed into the endosperm. As this occurs, the starch content of the grain increases and the fiber, which is contained primarily in the seed hull, becomes proportionally less of the whole kernel. Starch is more dense than fibrous carbohydrates. Consequently, grains that fill to plumper kernels and have greater starch and lesser fiber content often have greater test weights. Reynolds et al. (1992) determined the correlation coefficient between barley test weight and acid detergent fiber content to be -0.44 and between test weight and starch content to be 0.47. Interestingly, the correlation between these two chemical entities and test weight is very similar.

The relationship between test weight and animal performance is not clear. Mathison et al. (1991b) evaluated barley of 43, 59, 64, and 66 kg/hl in high concentrate rations fed to beef steers. The light barley had 9% less starch than the two heavier barleys. This difference, however, resulted in only a 2% reduction in organic matter digestibility for the light barley. There appeared to be a "plateau effect" as the two heaviest barleys were not more digestible than the 59 kg/hl barley.

When growth performance was measured, steers fed the light barley ration had similar dry matter intake and daily gain but required 6% more feed dry matter per unit gain than steers fed the heavier barley rations. Again, the higher test weight barley (64 kg/hl) produced no improvement in growth performance compared with the intermediate (59 kg/hl) barley. Similarly, Grimson et al. (1987) evaluated barleys weighing 47.8, 55.6, and 66.6 kg/hl in high concentrate rations (85% barley), and found no differences due to test weight for either dry matter intake or daily gain. However, a 1.2% increase in feed efficiency was observed for each unit increase in test weight from the low to medium test barleys. As in the previously cited study, they found no further benefit for the heavy versus the medium test weight barleys. It is unclear why this plateau effect occurs as barley reaches higher test weights.

Perhaps a clearer, more consistent relationship with animal response can be formulated with starch and fiber content than has been reported with test weight. Table 3 presents the results of two recently reported studies which evaluated barley varieties for diverse starch and fiber content. In the first study, Engstrom et al. (1992) evaluated six barley varieties which were fed in high grain rations to finishing beef cattle. The six varieties are arranged in Table 3 in ascending order according to the starch content, which ranged from 56.5 to 65.6%. This arrangement approximately ranks the varieties in descending order of acid detergent fiber content, which ranged from 9.7 to 5.7%. Varietal differences in starch content did not affect daily gain; however, feed efficiency (F:G, or feed DM per unit gain) was improved as the starch content of the barley varieties increased.

Interestingly, the ß-glucan content was positively correlated with starch content, and higher ß-glucan content barleys had improved feed efficiency. This was a significant finding indeed as ß-glucans are a soluble fiber and are regarded as undesirable compounds by monogastric nutritionists. Contrary to what is observed in monogastric animals, Engstrom et al. (1992) found ß-glucans to be highly digestible (98.1 to 99%) in cattle. Coefficients of determination between feed efficiency and ß-glucan, starch, neutral and acid detergent fiber, and ruminal digestibility were reported to be 0.62, 0.69, 0.73, 0.90, and 0.83. The correlation between starch content and ruminal digestibility (8 hours of digestion) was 0.96.

Ovenell and Nelson (1992) also evaluated six barley varieties, which are ranked in Table 3 from low to high according to starch content. Varietal differences in starch content were inversely related to neutral detergent fiber content. Differences in starch content did not result in differences in daily gain, but the ranking of varieties according to starch content did also rank the varieties exactly according to feed efficiency.

The findings of studies presented in Table 3 are particularly important as they clarify the relationship between chemical composition and animal performance. First, variability in barley quality may not result in differences in daily gain, although barley quality factors may be quite closely related to feed efficiency. Feed efficiency is widely regarded as the most economically important performance variable, therefore significant improvements in production efficiency of livestock could be achieved with barley with enhanced nutritive value. Research is required to determine if differences in milk production efficiency would occur which are similar to these differences in growth efficiency.

Second, test weight appears to be closely related to animal performance at the lower end of the scale, but test weight may not be a reliable index of animal performance at the upper end of the scale. Starch and fiber content, on the other hand, appear to be reliable predictors of animal performance across the entire quality spectrum. Future evaluation of barley should center on these chemical entities rather than on test weight. Convenient and low cost methods of starch or fiber analyses are required in the marketplace to replace the currently used test weight measurements. Near infrared spectroscopy offers one potential means of achieving this capability (Reynolds et al., 1992).

Hatfield et al. (1993) evaluated two barleys in rations fed to wether lambs. Ottus and Steptoe had starch contents of 52.7% and 56.7%, respectively. Rations were formulated to provide equal levels of total dietary starch such that the Ottus ration was 70% grain and the Steptoe ration was only 65% grain. Given this treatment design, barley variety had no influence upon intake or digestion. In an experiment with a similar treatment design, Grings et al. (1992) formulated barley and corn diets which were balanced to a equal level of dietary fiber using beet pulp. No dietary treatment effect was observed for dry matter intake, milk production, or milk composition. Brake et al. (1989) fed Holstein steers grass hay rations supplemented with barley or corn on an equal digestible energy basis (steers received either 1.0 or 1.07% of body weight daily as corn or barley, respectively). With this treatment

Table 3. Relationship between chemical composition and cattle growth performance.

Reference	Barley Variety	Nutritive or Growth Variable[a]				
Engstrom et al. 1992		ß Glucan, %	ADF, %	Starch, %	Daily gain, kg	F:G
	4	4.1	9.7	56.5	1.55	6.34
	1	3.5	8.5	61.2	1.49	6.35
	2	3.9	7.1	61.8	1.57	6.12
	3	4.1	6.7	62.0	1.53	5.97
	5	4.6	5.7	64.9	1.56	5.85
	6	4.8	6.3	65.6	1.56	5.92
Ovenell and Nelson 1992		CP, %	NDF, %	Starch, %	Daily gain, kg	F:G
	Steptoe	10.6	30.8	48.3	1.4	6.9
	Clark	12.4	29.8	49.4	1.4	6.9
	Cougbar	10.5	29.8	49.7	1.3	6.6
	Andre	11.4	27.3	50.7	1.4	6.5
	Harrington	10.1	25.6	52.5	1.4	6.4
	Camelot	10.5	25.3	53.6	1.4	6.3

[a]ADF = acid detergent fiber, F:G = feed DM per gain, CP = crude protein, and NDF = neutral detergent fiber.

formulation scheme, feed intake and organic digestibility were greater for the barley than the corn rations. These studies all appear to verify the theory that starch and/or fiber content are critically important in determining the nutritive value of grain.

Starch and Fiber Digestibility. Starch from cereal grains, such as barley, wheat, and oats, are more readily digestible by the ruminant animal than starch from corn or sorghum. This difference is particularly pronounced in the ruminal degradability of these different grain starches. Waldo (1973) provided an excellent review on the factors affecting starch digestion, citing barley starch as being 94% degradable in the rumen, whereas corn starch is only 78% degradable.

Herrera-Saldana et al. (1990) evaluated the degradability of corn, sorghum, barley, wheat and oats. One hour laboratory incubations of the grains with glucoamylase showed the greatest starch degradation for oats (28%), the lowest starch degradation for corn and milo (13 and 9%, respectively), and intermediate degradation for barley starch (18%). The same grains were incubated in nylon bags in the rumens of six cannulated beef steers. Assuming the grains would pass through the rumen at a rate of 6% per hour, Herrera-Saldana et al. (1990) determined that barley would be 78% ruminally available, while corn and sorghum would have ruminal availability of 54 and 38%, respectively.

These differences would obviously have a large impact on the proportion of grain starch that would be ruminally versus intestinally digested. While ruminal fermentation is associated with a certain concomitant level of methane production (energy loss), digestion of carbohydrates in the rumen has several distinct benefits compared with intestinal digestion.

First, ruminal fermentation of organic matter, particularly carbohydrates, may positively impact the protein status of the ruminant animal. Energy provided during fermentation is available for protein production by the ruminal microorganisms. Although other factors exist, ruminal microbial production is largely responsive to fermentable energy.

Second, greater total tract starch digestibility may occur when a greater proportion of starch is degraded in the rumen due to the limited capacity of the ruminant for intestinal starch digestion. Evidence of this phenomenon is often observed in the results of steam processing of grains. Steam flaking serves to gelatinize the starch, rendering the starch more ruminally fermentable. Steam flaking of corn usually produces enhanced starch digestibility and feed efficiency while steam flaking of barley, which is by nature highly fermentable, is usually not beneficial.

A reduced digestibility of the fiber component of a ration is a disadvantage of ruminal starch fermentation . Recent studies involving grain supplementation of forage-based diets has shown a reduced fiber digestion as grain is added to diets in excess of 25% of diet dry matter. This phenomenon is attributed to rapid starch fermentation in the rumen which results in reduced ruminal fluid pH. Barley is more rapidly fermented in the rumen than corn and grain sorghum, which may cause precipitous drops in ruminal pH. Leventini et al. (1990) reported reduced ruminal fiber digestion when 30% barley was added to grass hay. This effect was mediated by the addition of a ruminal buffer to the ration. Reynolds et al. (1993) observed trends of greater benefits from a ruminal buffer for barley than for corn-supplemented straw diets fed to beef cattle. It is reasonable, therefore, to assume that buffers are more critically important in barley supplemented rations for lactating dairy cows than corn supplemented rations.

The negative impact of starch fermentation upon fiber digestion becomes less important with higher levels of grain in the diet, such as with beef finishing diets. The fiber content of these diets becomes sufficiently low that reduced fiber digestion does not represent a great loss. However, a potential problem with high levels of barley in these diets would more likely be ruminal acidosis. The high fermentability of starch in barley may cause a precipitous drop in ruminal pH to a level which is harmful to the ruminal epithelium. Unfortunately, studies have not been reported which evaluate the acidosis-producing potential of barley compared with other grains. Growth benefits have been observed from the combination of highly with lowly fermentable grains in beef finishing rations (Stock et al. 1987).

Perhaps another important factor which may affect the energy availability of barley is the digestibility of the fiber constituent. The importance of fiber and starch content has been well established. However, the digestibility of the fiber component of barley has been largely overlooked. Aronen et al. (1991) reported barley fiber (hulls) were only 50.4% degradable following 10 hours of ruminal incubation compared with the 69.1% degradation of wheat millrun. Differences in fiber degradability among forages is quite well established and it would be logical to assume that similar differences occur among fibers found in grains. Research is warranted to determine the feasibility of enhancing the feed value of barley by improving fiber degradability.

Comparison of Barley with Other Grains

A knowledge of the compositional and starch degradability differences of grains helps in the understanding of the true differences in the nutritive value between grains. Such a comparison also requires a consideration of the type of ration being fed or of the production setting, whichever is most applicable. This section reviews current literature comparing barley with other grains as a supplement to forage-based rations, such as those fed to lactating dairy cows and growing beef cattle, and as the principle ingredient in high grain rations, such as those fed to finishing beef cattle.

Forage-Based Rations. Seoane et al. (1990) studied rations containing 60% grain of either barley or corn fed to steers. Digestibility of dry matter, acid detergent fiber, starch, and energy were greater for the barley rations. Kung et al. (1992) evaluated lactating dairy cow rations containing either corn silage or alfalfa hay as the forage (50%) and corn or barley as the grain concentrate (50%). Barley rations had greater organic matter and starch digestion in the rumen than corn and tended to have greater total tract organic matter digestibility (67.5 vs 64.2%).

Similarly, Rode and Satter (1988) fed corn or barley with long or chopped alfalfa hay in 75 or 25% forage rations. When long stemmed alfalfa was fed, barley increased ruminal organic matter digestion. More microbial protein but less feed protein (escape protein) entered the intestine with barley than with corn rations, therefore protein entering the intestine for digestion and utilization by the cattle was the same for barley compared with corn rations.

Hussein et al. (1991) compared the effects of barley with corn supplementation (39% of diet dry matter) when they were combined with either fish meal or soybean meal as protein supplements for wether lambs. Again, barley rations had greater organic matter digestibility in the rumen and tended to result in greater microbial protein production. When fed with fish meal, barley resulted in more total amino acids being absorbed from the small intestine for utilization by the lambs.

The results of these studies confirm the theory that barley feeding may improve the protein status of the ruminant animal compared with corn or other less ruminally degradable starch sources. This improvement would occur via more extensive ruminal fermentation resulting in greater microbial protein synthesis.

The different sites of digestion of grains may make no difference in animal performance. DePeters and Taylor (1985) observed the lack of difference in total tract dry matter and energy digestibility, when corn or barley was fed to lactating dairy cows, resulted in no differences in milk composition and milk yield. Dion and Seoane (1992) evaluated corn, barley, wheat and oats fed at 54% of the total diet dry matter. Corn rations actually had the lowest starch digestibility. No differences were observed among the grain diets for dry matter intake, daily gain, or feed efficiency. While too few animals were used in the experiment to identify significant differences (8 steers per treatment), the barley diet had a numerically greater digestibility and better feed efficiency than corn.

Grain-Based Ration. Modern beef cattle production has become more intensive in recent decades. Before being sold for slaughter, cattle are now routinely placed on high-energy (grain) finishing diets, usually for a period of at least four months. Little research has been published comparing barley with other grains in these high-grain finishing rations. In the U.S., corn and grain sorghum are the dominant grains fed during the finishing period. Data does suggest, however, that there are benefits for inclusion of barley in beef finishing rations.

In an extensive digestion experiment, Spicer et al. (1986) compared barley, corn, and grain sorghum in rations containing 82% grain. Of the three grains, sorghum had lower ruminal starch digestion, and lower N (crude protein) and starch digestibility, throughout the total digestive tract. While no statistical differences in total tract dry matter digestion were detected, the grains ranked as follows: corn > barley > grain sorghum. Barley was most extensively degraded in the rumen as evidenced by lesser undergraded protein leaving the rumen. This effect was counter-balanced by a greater amount of microbial protein leaving the rumen, thereby resulting in no difference among the grains in the total protein leaving the rumen to be digested in the small intestine. These data are similar to those presented in the previous section. While grains with diverse fermentability resulted in different types of protein (microbial and undergraded) flowing to the small intestine, the same amount of total protein was available for intestinal digestion.

A common practice in beef finishing programs is to feed a combination of grains rather than a single grain. Hill and Utley (1989) evaluated finishing rations (76% concentrate) with mixtures of 70% corn and 6% soybean meal, of 38% corn and 38% barley, and of 38% corn and 38% triticale. Digestibility of dry matter, organic matter, fiber and protein were equal with all three treatments. The lack of differences in digestibility paralleled the lack of differences in the rate and efficiency of growth. These data suggest a benefit of the higher protein content of barley compared with corn (Table 1) with barley effectively replacing the protein provided in soybean meal.

Burgwald et al. (1992) evaluated barley and corn in high grain rations fed to mature beef cows. No differences were observed in daily gain or feed efficiency. Yield grade, however, was greater for the barley ration, while corn-fed cows had numerically lesser loin eye area (73.3 vs 69.2 cm^2) and greater fat thickness (.53 vs .44 cm) than barley-fed cows. As consumers increasingly prefer leaner meat products, additional study is warranted to determine the carcass quality response to barley feeding.

Garrett et al. (1971) extensively evaluated effects of grain types and processing methods on cattle growth. Results of corn versus barley comparisons are presented in Table 4. Differences in animal growth performance and calculated net energy values were not detected between corn and barley. In fact, the values of the measured variables were remarkable similar. The response to steam vs. dry processing

Table 4. Comparison of barley and corn; dry- or steam-rolled on cattle growth and calculated energy values.[a]

	Corn		Barley	
Item	Dry rolled	Steam rolled	Dry rolled	Steam rolled
Dry matter intake, kg/day	9.15	9.82	9.29	9.24
Daily gain, kg/day	1.16	1.29	1.26	1.19
Feed dry matter:gain	8.19	7.79	7.50	7.97
Net energy, Mcal/kg				
Maintenance	1.88	1.86	1.91	1.89
Gain	1.20	1.18	1.24	1.25

[a]Adapted from Garrett et al. 1971.

was not significant, although numerical trends suggest some improvement due to steam processing of corn while there was no benefit due to steam processing of barley. Responses due to grain processing will be presented in greater depth in the following section.

Data presented in this section bring into question the discounted energy values for beef and dairy cattle used by the NRC for barley compared with corn (Table 1). While barley generally is not quite as highly digestible as high starch content grains, such as corn and grain sorghum, the greater ruminal fermentability may compensate in most feeding situations. This greater ruminal fermentability has proven benefits for both the energy and protein status of the ruminant animal.

Grain Processing and Storage

The method of processing and storage prior to feeding is another factor affecting the nutritive value of barley. It is unfortunate that the standard for grain processing and storage in the U.S. and in many parts of the world derives from experiments involving corn. Barley, however, presents an entirely different scenario based upon the nature or fermentability of the starch and the unique environmental conditions characteristic of where barley is grown and fed. The following section will present information on the physical and chemical processing of barley.

Physical Processing and Storage. The trend toward more intensive livestock production has required obtaining the maximum nutrient supply from feedstuffs. A popular method of achieving increased bioavailability of grains is dry processing or rolling, which renders the internal structures of the kernel more accessible to ruminal microbial and enzymatic attack. Because of its particularly thick and impermeable seed hull, barley may benefit from dry rolling more than other grains. Dry rolling improved the organic matter digestibility of barley from 52.5 to 85.2% (Toland 1976). This study further revealed that 48.2% of all whole kernels which were fed to beef steers were recovered in the feces, indicating that the animal has difficulty digesting unprocessed barley kernels. Similarly, Orskov et al. (1978) reported dry matter digestibilities of 67.2% for whole barley and 83.4% for dry-rolled barley. Rolled barley fed to beef steers had greater dry matter and energy digestibility than whole barley (Mathison et al. 1991a). This response was associated with only a numerical improvement in daily gain (1.38 vs 1.3 kg/day), but a highly significant improvement in feed efficiency (6.28 vs 7.25 units of feed dry matter per unit of animal gain) for rolled compared with whole barley. Economides et al. (1990) also reported improved feed efficiency in finishing cattle fed dry-rolled barley compared with whole barley, although no difference was observed for daily gain. Readers should note the similarity of response for dry rolling vs. unprocessed barley to that previously reported for high vs low starch content barley.

A more extreme method of physical processing involves applying of steam followed by either rolling or flaking of the grain. The moist heat serves to swell the starch granule and gelatinize the starch. This process effectively increases the ruminal fermentability of starch found in corn and grain sorghum (Waldo 1973), although the effect of steam processing on starch found in small cereal grains is less evident. Fiems et al. (1990) reported that steam flaking increased the ruminal degradability of corn. However, steam flaking actually reduced the ruminal degradability of barley and wheat. These findings were consistent with those of Grimson et al. (1987) and Mathison et al. (1991a), who reported no differences in the rate and efficiency of gain for cattle fed either dry-rolled or steam-processed barley. Morgan et al. (1991) observed improved growth performance for cattle fed steam-rolled barley compared with whole barley. However, a dry-rolled barley treatment was not included in the study. A possible benefit of the steam processing of barley may be the reduction of fines or flour which is commonly associated with the dry processing of barley. The presence of fines in high grain diets often results in rumen acidosis which may subsequently lead to liver abscesses. Grimson et al. (1987) reported 31% fewer liver abscesses in cattle fed steam-flaked rather than dry-rolled barley in finishing diets. A more cost effective means of reducing fines might be tempering (adding water) to the barley several hours prior to feeding (Combs and Hinman 1989).

The cooler, shorter growing season characteristic of many regions where barley grown is often not conducive to adequate field drying prior to grain harvest. Harvesting the grain early while it is still wet has the advantages of reducing field loss of grain and consequently improving grain yields (Kennelly et al. 1988b). Kennelly et al. (1988a) observed almost a 20% improvement in grain yield for early harvested barley. Feeding high-moisture, ensiled grain has often been associated with improved animal performance, although performance responses have not been observed with feeding high moisture barley (Kennelly et al. 1988a and 1988b). While milk yield and feed intake were not different, Kennelly et al. (1988a) observed ruminal degradation after 8 hours of incubation was actually lower for ensiled than dry barley. This is in contrast to other grains which are known to have increased ruminal fermentability following ensiling. Results of these studies indicate early harvest of barley may well improve grain yield, although improved animal performance following ensiling of high moisture barley should not be expected.

Chemical Treatment. This is a less consistent, and therefore a more controversial, method of grain treatment. Chemical treatment of barley has been examined using organic acids (Flipot and Pelletier 1980; Williams et al. 1983) ammonia and/or urea (Williams et al. 1983; Rode et al. 1986; Mandell et al. 1988; Mathison et al. 1989; Robinson and Kennelly 1989; Yaremcio et al. 1991; Bradshaw et al. 1992) sodium hydroxide (Greenhalgh and Petchey 1980; Orskov et al. 1980; Sriskandarajah et al. 1980; Orskov et al. 1981) and sulfur dioxide (Gibson et al. 1988; Mathison et al. 1988; Mathison et al. 1989). These compounds may be applied to accomplish any or all of the following three objectives: (1) preservation of high moisture grain; (2) decrease in the rate, but not the extent, of ruminal starch degradation to enhance the ruminal environment; and (3) improvement of the digestibility of the fibrous carbohydrates in grain.

The earliest chemical treatment experimentation was performed with sodium hydroxide. Sriskandarajah et al. (1980) reported a slower rate of ruminal degradability for sodium hydroxide-treated barley. They also found that lactating cows consumed more hay and had greater milk production when fed treated barley. Orskov et al. (1980) reported that organic matter digestibility improved from 61 to 83%, when 3% sodium hydroxide was added to barley. Other studies, however, show reduced dry matter and starch digestibility (Orskov et al. 1981) and reduced growth performance (Greenhalgh and Petchey 1980; Orskov et al. 1981) with sodium hydroxide treated barley.

A more popular recent method of chemical treatment has been the application of anhydrous ammonia, or ammoniation. Results from experimentation have been extremely mixed. Robinson and Kennelly (1989) fed dairy cow rations containing 38.5% high moisture barley of various levels of ammoniation. Ammonia treatment did not affect digestibility of organic matter, starch or fiber, but milk yield and total milk protein improved. Williams et al. (1983) reported improved dry matter digestibility with ammonia treatment. However, growth performance was compromised by virtue of lower feed intake of the ammoniated barley ration. Bradshaw et al. (1992) observe no benefit of ammoniated barley compared with dry rolled barley in both growing and finishing rations for beef cattle. While Mathison et al. (1989) reported less heating in ammonia treated high-moisture barley, Yaremcio et al. (1991) concluded that ammonia was not an efficacious preservative of high moisture barley and failed to enhance growth performance. Results of these ammoniation studies suggest proper management of air-sealed storage of high moisture barley is the most reliable means of assuring proper feeding value.

Experiments with sulfur dioxide treatment of high moisture barley have proven less than promising. While sulfur dioxide is effective in preserving high moisture barley (Mathison et al. 1988), sulfur dioxide failed to enhance lactational performance (Gibson et al. 1988) or growth (Gibson et al. 1988; Mathison et al. 1989).

Conclusions

The intent of this literature review is to present the results of research investigating the feeding value of barley grain. Particular emphasis is given to the relative value of barley compared with other feed grains in common feeding situations. The literature review focuses on research findings from the last ten years. While earlier research may have been well-designed experimentation, the results may not be representative of the type of barley that is available for livestock feeding today. Research findings presented throughout this review suggest that the feeding value of barley is very much on the par with other feed grains and that the current NRC values for energy may underestimate the true value of barley. In general, barley is one to two percentage units lower in digestibility compared with corn. However, the advantages of greater ruminal degradability of barley may offset this shortcoming. Current studies indicate growth and lactation performance are equal to corn in most livestock feeding situations.

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Feeding Value of Barley Grain for Sheep

Richard C. Bull
Department of Animal and Veterinary Science
University of Idaho

Introduction

The most important factor in the profitability of a sheep enterprise is an appropriate nutritional program geared to the type of sheep and the stage of production. Energy requirements determine the success of the nutritional program. Feedstuffs vary greatly from relatively poor to very rich in energy. Barley grain is rich in metabolizable energy. Sheep are ruminant animals which ferment a sizable portion of the diet in the first part of the digestive tract, the rumen-reticular area. It is in this part of digestion that the microorganisms (bacteria and protozoa) predigest the diet, producing beneficial products for the host sheep.

Much of the research literature on barley for sheep explores the relationship between the needs of the microbial population in the rumen and their contribution from this fermentation process to the needs of the sheep. This symbiotic relationship between the microbial population and the sheep is an important one for the sheep producer. The efficiency of feed conversion to meat or wool relies on this symbiotic relationship.

Barley as a Supplemental Energy Source

Pregnant Ewes. Evaluating the feeding value of barley for sheep during late pregnancy and lactation has been reported by Cloete and Brand (1990). They compared the feeding value of supplemental barley to oat and triticale grain at 500 g/head daily for ewes grazing wheat stubble pasture. All supplements tended to increase greasy and clean wool per unit of skin area, but the greatest effect ($P<.05$) was heavier lamb birth and weaning weights. Barley maintained higher ($P<.05$) average body weights of ewes during lactation than the unsupplemented feeds.

Wether Lambs. Various barley mixtures (25, 50, or 75% of the diet) in non-pelleted dried grass diets did not affect the feed intake by wether lambs (Tucker 1975). A 50% barley diet resulted in the highest energy intake and lamb performance. A metabolizable energy intake from 1.58 to 2.04 times maintenance requirements was the best for overall performance of the lambs.

One concern with using barley supplementation in high roughage diets is its possible effect on roughage organic matter digestibility of the forage component of the diet. There was an overall increase in intake of organic matter and energy consumption when supplemental (25 to 50%) barley is added to lamb diets. There was also higher energy from increased digestibility of overall diet organic matter with supplemental barley, as barley contains highly digestible starch. However, barley and other grains tend to reduce the proportion of fiber digestion in the rumen and increase the proportion of lower gut digestion, mainly in the small intestine. This reduction in fiber digestion becomes more pronounced when barley is in excess of 25% of the diet dry matter. The digestibility of cellulose may be reduced in the rumen with barley feeding. However, there is one report of a compensatory increase in cellulose digestion in the small intestine when barley is included at concentrations of less than 25% (Thomas et al. 1980).

Barley Processing

The physical processing of certain grains for feedlot cattle results is a well documented benefit for increased performance. However, feeding processed grain for sheep has not consistently improved lamb rate of gain or feed efficiency. In 75 to 85% barley diets, Hatfield et al. (1993) found starch to be 98% digested by lambs fed whole barley. In a similar trial Yoon et al. (1986a) found only slight differences in the feeding value of whole, rolled, or steam-rolled barley to sheep in a 23:77 ratio of hay to concentrate diets when comparing them with cracked corn as the grain source. Steam-rolled barley diets increased the amount of retained nitrogen, the ratio of N passing to the abomasum to total N intake, and the non-ammonia nitrogen flow compared with whole or ground barley or cracked corn. There was no apparent difference in the amount of organic matter digested in the rumen and the overall organic matter digested in the gastro-intestinal tract with barley processing. Steam-rolled barley apparently increases the efficiency of microbial protein synthesis in sheep, but has little effect on other digestive processes.

For sheep consuming common feedstuffs, the flow of non-ammonia nitrogen to the small intestine consists of microbial protein which is produced during rumen fermentation and dietary proteins by-passing rumen fermentation. The synthesis of microbial protein is limited by the amount of energy made available by anaerobic fermentation and ammonia concentration of the rumen. The efficiency of microbial protein synthesis requires the efficient utilization of degraded dietary nitrogen and necessitates that fermentable energy from the organic matter is released at a rate that matches the synthesis abilities of the rumen microbes (Smith 1979). Both dry-rolled or steam-rolled barley diets yielded higher total rumen bacterial protein synthesis than whole barley or cracked corn diets (Yoon et al. 1986b). Steam-rolled barley resulted in higher abomasal digesta content of total non-essential and essential amino acids than did other processing or cereal sources. The results of this study suggest that the energy release from steam-rolled barley was utilized more efficiently for microbial protein synthesis than that from cracked corn, or unprocessed or dry-rolled barley. This could be important when dietary protein is limiting and microbial protein synthesis must provide the major source of essential and non-essential amino acids to the sheep.

Feeding whole barley to lambs on high energy diets could reduce the severity of ruminal pathology because of acidosis. If whole barley feeding reduces acidosis in the rumen, a more healthy ruminal environment could aid in maintaining feed intake, fiber digestion, and growth. In general, lambs are more susceptible to acute acidosis than cattle (Huntington 1988).

Restricting Feed Intake

Many researchers have found a slight improvement in feed efficiency of cattle (Hicks et al. 1990; Old and Garrett 1987) and sheep (Glimp et al. 1989) by restricting intake of high-energy diets. Some of this increased efficiency could be a reduction in acute acidosis or grain overload. *Ad libitum* intake of high grain (energy) diets increase the incidence of lactic acidosis and bloat in lambs compared to restricted intake diets (Plegge 1986; Zinn 1986; and Glimp et al. 1989). An intake restriction of at least 70% of *ad libitum* increased total tract organic matter and starch digestion, while 78% restriction did not (Hatfield et al. 1993). Feed restriction will reduce growth rate, thus requiring an additional time to reach market weight.

Increased yardage costs could reduce any advantage of the increased feed efficiency from restricting feed intake.

The reduction in feed wastage is another advantage of restricted feeding over feeding of an *ad libitum* diet. Typically, feed wastage is higher when lambs have unlimited access to feed.

Effect of Barley on Wool Production

Wool growth has been shown to be influenced by the source of energy and by the protein content of the diet. When diets were marginal in crude protein, wool growth rates varyed greatly for high-barley diets (Hynd and Allden 1985). Such high variation in wool growth was eliminated by feeding a high protein source. Wool growth was closely related to protein flow from the rumen on the high-barley diet and for high-barley and lucerne diets when considered together.

Conclusions

In general, barley is on par with other high-energy grain sources for sheep. Current National Research Council (NRC) values for barley understate its true nutritive value for sheep. Barley composition is highly variable, especially for energy, fiber, and protein content. Because of its variability, lamb feeders should chemically evaluate the barley source since variety and growing conditions may alter its nutritional value. There is little advantage from using processed barley for sheep. If barley is processed, the kernels should not be finely ground where the starch would be floured. Sheep have a problem of acidosis on high energy diets with finely processed grains. Feeding whole barley reduces the incidence of this pathological condition. Barley is more digested in the rumen-reticular areas of the stomach than are corn and sorghum. This increases the synthesis of microbial protein, which enables the animal to produce wool, milk, or muscle. The overall performance of sheep consuming good quality barley should be equal to or greater than those using other cereal grain sources.

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PNW Barley Research Clearinghouse
1200 NW Front Ave., Suite 520
Portland, OR 97209-2800
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