APPLICATION OF OUR UNDERSTANDING OF BARLEY QUALITY TO DAIRY FEEDING MANAGEMENT

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The challenge in formulating ruminant diets containing barley is to take advantage of potentially greater production of rumen microbial protein without reducing dry matter intake and fiber digestion that can negate gains in microbial protein production. This review attempts to identify those methods that optimize barley use in dairy rations.

In research studies that compared corn and barley in diets for dairy cows, milk yield and dry matter intake (DMI) have tended to favor diets containing corn (Weiss et al., 1989; McCarthy et al., 1989; Overton et al., 1995; and Casper et al., 1999) although some studies have found no difference (Khorasani et al., 1991; Grings et al., 1992) or no difference between corn and barley when fed to cows in mid-lactation (Kincaid et al., 2000). Even though corn is the standard used in most feeding studies with barley, interpretation of results is confounded by differences in chemical composition of the diets and processing of the grains. Because barley has more fiber and protein, and less starch than corn, direct comparisons of corn and barley in dairy rations are somewhat complicated. Sources of fiber and protein often are added to diets containing corn to create diets equal in total fiber and crude protein to the barley diets (Overton et al., 1995). Few studies have attempted to standardize the starch content among dietary treatments. Thus, the digestibility of the supplemental fiber and protein, and total content of dietary starch, influence the results. In addition, barley is affected by variety and environmental conditions to yield considerable variability in its chemical composition.

Digestion of Starch, Protein and Fiber

Ruminal degradation. Starch and protein in barley are more extensively degraded in the rumen compared to corn (Theurer, 1986; McCarthy et al., 1989; Overton et al., 1995). For example, McCarthy et al. (1989) reported an apparent ruminal digestibility of 77% for starch in barley, compared to an apparent ruminal digestibility of 55% for starch in corn. Protein in barley also is ruminally degraded faster and to a greater extent than protein in corn, accordingly, less non-

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ammonia, non-microbial N passes to the duodenum of cows fed barley (McCarthy et al., 1989; Overton et al., 1995). Surprisingly, concentrations of ammonia in ruminal fluid often are lower in cows fed barley than corn (McCarthy et al., 1989; Overton et al., 1995; Casper et al., 1999) even though the barley protein is more extensively degraded. Two possible explanations for reduced ammonia in ruminal fluid of cows fed barley are: 1) that barley increases the amount of water in the rumen; and 2) there are faster rates of microbial protein production with barley.

Measurements of protein and amino acids flowing into the duodenum of cows fed corn or barley are often confounded by differences in DMI of cows. For example, Table 1 lists flow of amino acids into the duodenum of cows fed diets containing 49% barley or 44% corn; clearly more amino acids entered the duodenum of cows fed the corn diet. However, the percent microbial N in the duodenum was greater for barley than corn, i.e., corn had more escape protein and barley yielded proportionately more microbial protein. Also, cows fed the corn diet ate 3.3 more kilograms of DM daily. In contrast, in a study (Harrison, 1999) in which DMI were similar between cows fed corn and diets with 27% barley, flow of individual amino acids into the duodenum was at least equal between the corn and barley diets, and greater for some barley varieties (Table 2).

Barley grain contains 15 to 20% hulls, which are greater than 70% neutral detergent fiber (NDF) and poorly digested in the rumen. Dietary fiber is less extensively degraded when barley is fed (DePeters and Taylor, 1985; Weiss et al., 1989; Overton et al., 1995), perhaps because the fiber in barley is inherently less digestible or because the more rapid ruminal fermentation of starch in barley causes a greater drop in ruminal fluid pH and, hence, the lowered pH retards fiber digestion.

Total tract digestibility. Although total tract DM digestibility (DMD) is similar between diets containing corn or barley, diets with barley have higher starch and lower fiber digestibilities. Both McCarthy et al. (1989) and Overton et al. (1995) reported total tract digestibility of starch in barley diets was 96-97% whereas the digestibility of starch in corn diets was 91-93%. McCarthy et al. (1989) found the NDF digestibility was 36% for barley diets and 44% for corn diets. Similarly, Overton et al. (1995) reported the NDF digestibility was 46% for barley and 52% for corn diets.

Barley Varieties

Few published dairy studies have characterized the dietary barley by variety and chemical composition even though barley varieties differ significantly in starch, fiber, protein, and feeding value (Hepton et al., 1995; Khorasani et al., 2000). Differences in chemical composition among barley varieties used in some lactation diets at the University of Idaho and Washington State University are listed in Table 3. Although most of the variation in digestibility of barley is due to bulk density, starch content, and kernel weight (Khorasani et al., 2000), differences exist within barley varieties in the digestibility of starch and fiber. For example, Harrison (1999) reported the total tract digestibility of starch from barley diets differed for barley varieties with a low of 87.9% for Baroness to a high of 96.2% for Idagold. Sanchez et al. (1997) found the *in situ* DMD of hulls differed among barley varieties: 32% for Baroness hulls, 42% for Idagold hulls, and 34% for Steptoe hulls. Similarly, Hepton et al. (1995) found Steptoe hulls had lower *in situ* DMD than hulls of Colter, Lud and Gallatin barleys.

Grings et al. (1992) reported no difference in milk yield of cows fed barley of different bushel weights (44, 49, and 53 lb/bu). Similarly, milk yield of cows fed barley and hull-less barley was similar even though chemical compositions of the barley were different (Yang et al., 1997) because the hull-less barley had a lower digestibility. In a feeding study that compared multiple varieties of barley to corn, milk yield of mid-lactation cows fed Steptoe was less than for cows fed Baroness, Idagold, or corn (Sanchez et al., 1997). In a subsequent metabolism study using cows with ruminal and duodenal cannulas, Harrison (1999) reported cows fed Harrington and Idagold barley tended to yield more milk than cows fed Baroness, Steptoe or corn.

Percent Barley in Diets for Lactating Cows

The percent of barley in diets used in feeding trials has varied markedly. Although cereal grains typically comprise about 30% to 40% of diets for lactating cows, some studies have included barley at 50% of the diet. When cereal grain has constituted 50% of the diet, milk yield and DMI has been higher for cows fed corn than for cows fed barley (Weiss et al., 1989; Overton et al., 1995). The upper level for barley inclusion without affecting milk yield appears to be about 33% of DMI, or about 50% of the concentrate. An exception may be cows in mid or late lactation that cope better with high concentrate diets (Kincaid et al., 2000; Khorasani and Kennelly, 2001). Undoubtedly, associative effects with other dietary ingredients influence the results of the studies, e.g., inclusion of corn silage versus alfalfa haylage, whole cottonseeds, wheat mill run, and other byproduct feeds, and supplemental fat sources. In fact, silage may affect ruminal fermentation more than the concentrate source when silage constitutes 50% or more of the total diet (Keady and Mayne, 2001).

Grain Processing

When barley is fed to cattle, processing is needed and numerous processing methods have been tried. These include: grinding; pelleting; dry rolling; steam rolling; steam flaking with thick, medium and thin flakes; tempering, fed whole; tempering, fed rolled; roasted, then dry rolled; roasted, the tempered and rolled; cubed; expanded; and rolled barley ensiled with fresh forages. Steam-rolling of barley is probably the most common processing method, however, the final product of steam-rolling and flaking varies with the amount of applied steam and rolling pressure (Yang et al., 2000b). Disruption of the protein matrix surrounding starch occurs during steam-rolling and flaking, increasing ruminal fermentation of starch and total tract digestibility of starch. In feeding trials with dairy cows, results for steam-rolled barley generally have been better than for dry-rolled barley (Theurer, 1986); and medium steam-flakes preferable to coarse or thin steam-flakes (Plascencia et al., 1998). Cows fed flat barley flakes, compared to medium-flat flakes, had lower DMI and longer periods of time when the ruminal pH was < 5.8 (Yang et al., 2000b). When tempered, rolling of the barley is preferable to feeding the whole grain (Christen et al., 1996).

Supplementation of Barley-Based Rations

Dietary Buffers. Compared to corn, barley has a faster rate of starch fermentation in the rumen, thus, use of dietary buffers to limit the reduction in ruminal pH seems advisable. When steers were fed 30% barley, a dietary buffer increased DMI (Reynolds et al., 1993). In studies in which milk yields were comparable between cows fed corn or various barleys, dietary buffers were included (Grings et al., 1992; Kincaid et al., 2000). However, there are other studies in which performance of cows fed corn was better than cows fed barley and buffers also were included in the diets (Overton et al., 1995). Without dietary buffers, there tends to be lower ratios of acetate to propionate in ruminal fluid of cows fed barley diets compared to cows fed corn diets (Harrison and Kincaid, 1993). In addition to improving DMI, dietary buffers can prevent milk fat depression in cows fed high-concentrate diets (Khorasani and Kennelly, 2001).

Protein. Several studies have tested dietary sources of ruminally undegradable protein on milk yield of cows fed diets containing barley (Table 4). Protein supplements have included fish meal (McCarthy et al., 1985), extruded soybeans (Casper et al., 1999), blood meal (Kincaid et al., 2000) and protected dl-methionine (Casper et al., 1988). The only positive response reported was an increase in milk protein percentage of cows supplemented with 15 g of dl-methionine (Casper et al., 1988). The lack of response in milk yield of cows fed these barley-based diets containing supplemental undegradable protein indicates that dietary protein was not the limiting factor to increased milk yield of these cows. However, further work on supplemental protein is needed with cows producing over 40 kg of milk per day.

Enzyme addition. Because less fiber digestion occurs in cows fed barley compared to corn, the addition of cellulases has been tested to enhance fiber digestion. Fibrolytic enzymes (xylanase and cellulase) have increased total tract DM digestibility and milk yield (Beauchemin et al., 1999; Yang et al., 2000a). Lewis et al. (1995) reported increased DMI and milk yield of mid-lactation cows fed barley diets containing fibrolytic enzymes, however, neither DM nor NDF digestibility were improved by the fibrolytic enzymes. Because some exogenous enzymes remain active during ruminal fermentation and may survive passage to the lower intestinal tract (Morgavi et al., 2001), there appears to be considerable potential to improve total tract digestibility of fiber with use of exogenous enzymes

Barley as a Silage Additive

Another method to feed barley to lactating cows is to add rolled barley to fresh forage at the time of ensiling (Harrison et al., 1994). Barley absorbs moisture from the forage and adds fermentable carbohydrate. In a series of studies conducted at Washington State University, the added barley (100 and 150 g/kg wet wt) particularly improved fermentation characteristics of unwilted alfalfa, although added barley had only minor effects on fermentation of corn silage. The *in vitro* DM disappearance of both the alfalfa and corn silages were increased by added barley at time of ensiling.

Phosphorus

Most P is present as phytin-P in grains, fortunately, near complete hydrolysis of phytic acid normally occurs quickly in the rumen. Compared to corn, barley contains more P (0.30 vs. 0.39%), and assuming P availabilities are similar between corn and barley, this means less supplemental P is needed in ruminant diets containing barley. Recently, Guyton et al. (2000) reported that sources of more digestible starch decrease P excretion, however, P availability in corn was higher than barley. Possibly, factors such as cud chewing, salivary flow, total P intake, microbial protein synthesis, and milk yield influence the digestibility of P in grains.

Calf Starter Rations

Barley can constitute the main grain in calf starters and yield comparable feed intakes and ADG to corn, however, processing method is very important. For best results with barley in calf starters, the starter should be textured with half the grain fed steam-rolled, and half the grain incorporated into the pellet (Kincaid et al., 1993). When the starter is fed as a complete pellet, feed intakes are better for calves fed corn than barley. Whether differences in feed intakes are due to palatability, the pattern of starch digestion, or physical differences in the fiber is not known.

Conclusion

When barley is included in dairy diets, recommendations are to process the barley as steam-rolled, medium steam-flakes, or tempered medium rolled-barley; to limit barley to about 35% of the total ration or 50% of the concentrate; and to use a dietary buffer. Although supplementation with sources of ruminal undegradable protein has not increased milk yields, work with high-producing cows is needed. Further progress in use of barley in dairy rations is anticipated from improved processing of barley, development of barley varieties that contain either more starch or a more digestible fiber, and by selective addition of fibrolytic enzymes to diets.

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TABLE 1. Amino Acid Flow Into The Duodenum of Cows Fed Barley or Corn Based Concentrates[1].

	Dietary Treatment[2]		
Measurement	**Corn**	**Barley**	***P*** **<**
DMI, kg/d	24.2	20.9	.005
N Intake, g/d	567	504	.03
Total flow, g/d			
N	685	620	NS
Microbial N	294	310	.13
Methionine	81	68	.03
Lysine	234	229	NS
Leucine	388	279	.004
Isoleucine	192	167	.02
Histidine	80	66	.03
Phenyalanine	190	162	.02
Microbial N as % of NAN[3]	44.3	51.8	.001

[1]Adapted from McCarthy et al., 1989.
[2]Both diets contained 15% CP with soybean meal as the main source of supplemental protein.
[3]Nonammonia nitrogen.

TABLE 2. Effect of Barley Variety on Flow of Amino Acids into the Duodenum of Cows[1].

	Dietary Treatment				
	Corn	**Baroness**	**Harrington**	**Idagold**	**Steptoe**
DMI, kg/d	19.1	19.4	18.7	19.4	19.4
N intake, g/d	608	649	640	608	631
Total flow, g/d					
N	295	321	307	339	311
Microbial N	142	151	142	170	161
Methionine	18.9[d]	18.9[d]	21.1[bc]	22.4[ab]	19.8[cd]
Lysine	65.7[d]	64.8[d]	73.7[bc]	79.2[ab]	71.3[cd]
Leucine	101.6[cd]	96[d]	109[bc]	113[ab]	101[d]
Isoleucine	56.7	56.3	66.8	58.7	56.9
Histidine	26.4[d]	26.0[d]	29.0[bc]	30.5[ab]	27.7[cd]
Microbial N as % of duodenal N	48	47	46	50	52

[1]Adapted from Harrison (1999).

[abcd]Means followed by different superscripts are different, $P < 0.05$.

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TABLE 3. Chemical Composition of Barley Varieties and Corn Used in Lactation Diets at Washington State University and the University of Idaho.

Grain	CP	Starch	NDF	ADF
	-----%-----			
Corn	9.5	66	9.3	1.9
Baroness	12.2	64.1	29.7	7.8
Harrington	14.1	61.8	32.5	7.6
Idagold	12.0	58.6	24.6	7.1
Steptoe	11.3	58.4	37.9	10.5

TABLE 4. Protein Supplements for Cows Fed Rations Containing Barley or Corn

Percent barley in diet	Protein supplement	4% FCM[a]	DMI[1]	Reference
49%	Fish meal, 3%	32.3 kg	20.5 kg	McCarthy et al., 1985
42.5%	Extruded soybean meal, 10.6%	19.1 kg	20 kg	Casper et al., 1999
26%	Blood meal, 1%	40 kg	28.6 kg	Kincaid, 1999
33%	dl-Methionine, 15 g/d	25.9 kg[b]	17.7 kg	Casper et al., 1988

[a]No treatment differences in fat-corrected milk (FCM) yield or DMI within the individual studies.
[b]The dl-methionine supplement increased milk protein percentage, $P < 0.05$