APPLICATION OF OUR UNDERSTANDING OF BARLEY QUALITY TO BEEF FEEDLOT MANAGEMENT

Dan D. Hinman and Sharon J. Sorensen
Department of Animal and Veterinary Sciences
University of Idaho
Caldwell Research and Extension Center

INTRODUCTION

The topic of barley quality and processing techniques has been addressed by numerous presentations during the past few years. This presentation will review some older research studies, as well as some newer aspects of barley quality and processing as it relates to finishing beef cattle on high grain diets. The evaluation of barley grain quality has been discussed for over 40 years, and yet we still do not have a definitive test for barley quality.

BARLEY QUALITY

Visual evaluation of barley grain is the simplest measure of quality used, however this method lacks consistency from one evaluator to the next. Weight per volume is the next method most often used and the simplest measure of quality available in field applications. Weight per volume, often called test weight or bushel weight, is expressed as pounds per bushel, or in metric as kilograms per hectoliter. The conversion from metric to English (bushel weight) is to multiply kg/hL by 0.776. Bushel weight and bulk density are indirect measures of the fiber and starch content of grain.

Weight per volume or bulk density measurements are subject to misinterpretations due to operator and equipment error, barley variety, and foreign matter contamination. Operator and equipment error should not be large concerns if the operator is trained properly and the correct equipment is used. Standard procedures and equipment should always be used in all research studies and field investigations. Barley variety may cause some errors due to the presence of awns and differences in hull thickness. Bulk density measurements should always be determined on

Proceedings of the 36th Annual Pacific Northwest Animal Nutrition Conference. October 9-11, 2001. Boise, ID, pp. 127-158.

cleaned grain to eliminate variation due to dirt, rocks or foreign material such as weed seeds, insects and straw.

Reviews of research on the influence of barley bulk density on beef cattle performance usually suggest that there is not a consistent relationship between barley grain bulk density and beef cattle performance. Many of the concerns expressed in the previous paragraph are implicated in this conclusion. The procedural and equipment aspects are evident and will not be discussed further in this paper.

Thomas, et al. (1962), compared light (45 lb/bu) and heavy (50 lb/bu) bushel weight barley with and without additional protein supplements (Table 1). The experimental design employed only four pens of steers, therefore, statistical comparisons are limited. However, gain was improved by 2.6% and feed efficiency by 4% when heavy barley was compared to light barley. Variety of the barley was not identified in this paper. Hinman (1978) compared Steptoe barley of differing test weights (Tables 2 and 3). Composition of the barley was related to the bulk density measurements. As bushel weight increased, grain protein levels decreased. Crude fiber levels tended to decrease and starch percentages tended to increase. Daily gain was higher for the heavy barley compared to the lightest barley ($P < .05$). Feed per unit of gain linearly increased as test weight decreased. This is reflected in the calculated NE values for the barley grain. Net energy values were calculated using the methodology outlined by Zinn, et al. (1996). Reflecting the performance differences between the heaviest barley (51 lb/bu) and the lightest barley (42 lb/bu), the heavy barley was worth $15.70 more per ton than the lightest barley.

Jimenez (1978) reported on unpublished data from C. J. Elam and J. W. Algeo, 1963, comparing 42, 46 and 49 lb/bu barley. Fiber levels increased as bushel weight decreased, similar to that reported by Hinman (1978). Elam and Algeo conducted a digestibility study with six heifers, and concluded that the organic matter digestibility was significantly higher (4.3%) for the 49 lb/bu barley than for the other barley. Jimenez calculated that the heavy barley was worth $10.60 more per ton than the lightest barley used in this study.

Canadian workers also conducted several cattle feeding and digestion studies comparing barley density to animal performance. Their work partially disagrees with the previous studies, with a less definite relationship between barley bulk density measurements and animal performance.

Grimson, et al. (1987) compared three different bushel weights (37, 43, and 51 lb/bu) in high concentrate diets (85% barley) fed to yearling steers (Table 4). Bushel weight had no effect on average daily gain or feed intake. Feed efficiency was poorer for the light barley compared to the medium and heavy barley (feed:gain 5.80, 5.32 and 5.26 for the light, medium and heavy bulk density barley, respectively). The authors did not indicate barley variety or starch content of the different bulk densities, however ADF values were similar suggesting starch content may also have been similar. This would suggest animal performance would vary little when fed these different bulk densities.

Mathison, et al. (1991) also compared barley of various bulk densities (33, 46, and 50 lb/bu). Two varieties of barley were used in this study and chemical analysis would indicate that both of the two heaviest lots were nearly identical in crude protein, ADF and starch (Table 5). This would suggest that animal performance would not differ when fed these barley varieties. Bulk density measured by bushel weight was most likely influenced by variety and contamination from foreign materials. Comparisons of the light and the two heavy varieties indicate a slightly lower daily gain and a poorer feed conversion for the light barley.

Light bulk density barley usually is comprised of a greater variation in kernel size, and is therefore more difficult to process than barley of uniform kernel size. Small and shrunken kernels will often bypass the rollers, or if the rollers are set to process the thin kernels, the larger kernels are over processed. Since grading standards are listed with singular bulk density measurements, grain is often blended from light and heavy barley to achieve an intermediate bushel weight. Hinman, et al. (1995) studied the influence of barley bulk density and the blending of barley of differing bulk densities on the performance of finishing beef cattle. Harrington barley grown in southeast Idaho was purchased from several growers who could provide light, medium and heavy barley (35, 44 and 52 lb/bu, respectively). From the light and heavy barley, three additional bulk density blends were evaluated (48, 45, and 38 lb/bu) (Table 6). Daily gain (Table 7) decreased linearly as bulk density of the barley and blends decreased, with the daily gain for the heavy barley being greater than that for the lightest barley ($P < .05$). Dry matter intake was not influenced by barley bulk density. Feed efficiency was improved for the heavy bulk density barley when compared to the 45 lb/bu blended barley and the 35 lb/bu barley. The blending of the different bulk densities numerically reduced the feed efficiency compared to single lot barley.

Hepton, et al. (1995) compared four barley varieties in a study to evaluate the influence of hull fiber levels on the digestibility of barley grain (Table 8). Hull percentage was higher for Steptoe than for the other three varieties. A later planting date tended to reduce hull percentage. Higher fiber content and lower starch content were evident in these varieties. Hulls from Steptoe barley were also less digestible than for the other three varieties. This paper describes some of the variation between varieties and the influence that growing conditions may have on barley grain composition.

BARLEY VARIETY COMPARISONS

Many studies have been conducted in the past few years comparing barley varieties. Some studies have evaluated animal performance and others have used laboratory analysis and *in vitro* or *in situ* comparisons. As these studies are numerous, this review will include results from a limited number. Engstrom, et al. (1992) compared six lots of unidentified barley for *in situ* degradability and feedlot cattle performance. Significant variations in chemical and bulk density were noted for the six lots of barley (Table 9). No differences in animal performance were detected when these six lots of barley were fed to finishing beef cattle (Table 10). The authors state that the chemical and bulk density measurements conducted on the barley samples included any foreign material present, however, they do not identify the amount and nature of the foreign material. It is difficult to assess the influence of the foreign material on the data presented.

Ovenell, et al. (1993) and the later publication of Ovenell-Roy, et al. (1998) evaluated the performance of finishing beef cattle fed six different barley cultivars grown in the dryland Palouse area of Idaho and Washington (Table 11). Feed conversion favored Harrington and Camelot barley, with Steptoe and Hesk having poorer feed conversions. Both of the later cultivars were lower in test weight and starch content and higher in fiber than Harrington and Camelot. Zinn, et al. (1996) evaluated the comparative feeding value of hulless and covered barley in beef finishing diets (Table 12). Feed intake was lower for the hulless barley than for the covered barley, while diet NE was greater for the hulless barley. The hulless barley had a higher percentage of starch, crude protein and bulk density and a lower ADF percentage than the covered barley. Hinman (1979) compared malting and feed varieties of barley in finishing beef cattle studies. The malting barley had higher bulk density and fiber levels and lower protein levels than the feed barley. The most evident difference was in the feed efficiency, with the heavy bulk density grain having an improved feed efficiency.

The literature on variety comparisons is quite extensive and this review will not list them all. Head-to-head comparisons of varieties can be biased if some quality measurement during the selection of the barley source is not used to eliminate variability such as starch, fiber, crude protein and bulk density.

Surber, et al. (2000) predicted barley feed quality for beef cattle from laboratory analyses (Table 13). *In situ* dry matter disappearance (ISDMD) was negatively correlated to daily gain (r = -.36, P < .007), NE_m and NE_g (r = -0.59, P < .001; r = 0.60, P < .001, respectively) and feed efficiency (r = -0.37, P < .007). Barley starch content was positively correlated with NE_m and NE_g (r = 0.34, P < .02; r = 0.37, P < .01, respectively). Feed efficiency could be predicted from NE_m, starch and ISDMD (R^2 = 0.66, P < .001). Selection of barley grain for low ISDMD, low ADF, high starch and large particle size could be used to improve feed quality characteristics. All barley used in this study was dry rolled and made up 80 to 85 percent of the diet. Other comparisons of barley grains by Sanford, et al. (2000) determined that calculated DE content and DM digestibility were positively correlated (P < .05) with starch content (r = .73 and .77, respectively) and negatively correlated (P < .05) with ADF content (r = -.71 and -.76, respectively). In this study, bulk density was not correlated with barley DE or DM digestibility (Table 14).

Khorasani, et al. (2000) evaluated sixty cultivars of barley to determine *in situ* degradation characteristics. From the *in situ* studies, they developed regression equations to assist in the selection of cultivars based upon bulk density, crude protein, starch, and kernel weight. The effective degradability of dry matter (EDDM) was determined and the correlation coeffficient was significant for the EDDM when the bulk density, kernel weight and starch content were included (P < .01, R^2 = 0.70). A regression equation was obtained to predict EDDM (EDDM = 34.1 + 0.21 TWT - 0.10 KWT + 0.69 starch). They observed that the chemical composition and bulk density measurements could be used to predict the EDDM of different barley cultivars. Bowman, et al. (2001) developed a ruminal DMD technique to compare barley cultivars in large-scale evaluations. These techniques will assist in the development of new barley varieties that should have greater feeding values than the varieties currently being used.

RELATIVE FEEDING VALUE OF BARLEY

The relative value of barley as a feed grain is usually compared to the energy values of corn. Zinn (1993) compared steam-flaked corn to dry-rolled barley, steam-rolled barley, coarse-roll, and steam-rolled barley, thin-roll (Table 15). The comparative feeding values of dry-rolled barley, steam-rolled barley, coarse-roll, and steam-rolled barley, thin-roll used in this study were 90, 92 and 96% the value of steam-flaked corn. The variety of barley used in this study was UC-476, however, no other measure of barley quality was reported except for a starch content of 55%. This level of starch in barley grain of unknown bulk density would likely be in the mid to high 40's in lb/bu.

In a similar study, Rodriguez, et al. (2000), found that the net energy-gain values for steam-flaked barley were underestimated by about 10% in the 1996 NRC tables.

Milner, et al. (1995) formulated isocaloric diets from corn and three barley varieties. In an 84-day study, there were no differences in average daily gain between the corn- and barley-fed steers (Table 16). Steers fed Steptoe barley diets gained faster than those fed Harrington and Morex barley. No differences were noted between barley varieties. In a related study, Milner, et al. (1996), the performance of finishing beef cattle fed corn was compared to those fed three barley varieties (Table 17). Isocaloric diets formulated from corn, Gunhilde, Harrington, and a Gunhilde-Harrington mix were studied. Feed: gain values in a 96-day finishing study were lower for the barley fed cattle than for those fed corn. Estimated grain NE_m and NE_g were higher for barley (2.15 and 1.48 Mcal/kg, respectively, $P< .10$) than for corn (2.04 and 1.39 Mcal/kg, respectively). Barley of a similar bulk density of 48.5 lb/bu was used in this study.

These beef cattle finishing studies continue to suggest that the NE values commonly used for barley (NRC, 1996) underestimate the value of barley as a feed grain. Across the cited studies it is also apparent that when barley varieties of similar bulk densities are compared in head-to-head studies, differences in animal performance are minimal.

BARLEY PROCESSING

In recent years there have been many reviews on grain processing and the influence of grain processing on the performance of finishing beef cattle (Galyean and Malcolm, 1991; Theurer, et al. 1996; Owens, et al. 1997; and Mathison, 1996). This paper will not attempt to again review all the studies already covered, however, a review of recent work and those with current application will be discussed.

Historically barley grain was dry rolled or cracked prior to feeding. The inherent problem of fines and digestive disturbances led us to study the effects of steam-rolled, steam-flaked, and then temper-rolled, and more recently temper-roasted-rolled barley. Many of the reviews above compared the relative value of steam rolling versus dry rolling with mixed performance results. In recent years steam flaking has been reported to increase the energy values of barley grain (Zinn, 1993). Flake thickness appears to be critical to achieving improvements in animal performance and the resulting improvement in energy values (Table 15). Research studies over the past 40 years have not flaked the steam-rolled grain to a level that stimulated animal performance improvements. Improvements in ruminal and total tract starch digestion are found with steam flaking. Also decreased ruminal methane loss and enhanced ruminal N efficiency were noted.

Hinman and Combs (1983) compared dry-rolled barley to temper-rolled barley in a beef cattle finishing study (Table 18). Increased average daily gain, feed intake and a trend for improvement in feed conversion were noted. Barley grain in this study was tempered by the addition of cold water to bring the moisture level of whole barley to 18%. Hironaka (1981) also found that temper-rolled barley improved the performance of finishing beef cattle fed high barley diets (Table 19). Dry-rolled grain was found to have finer particle size than tempered grain. Average daily gain was higher for cattle fed tempered grain than those fed dry-rolled grain, and numerical improvements in feed intake and feed efficiency were noted.

Mathison, et al. (1997) studied both dry-rolled and temper-rolled barley in a high concentrate diet (Table 20). In addition, grains were slightly rolled, medium rolled or crushed. The dry-rolled barley used in this study contained 13% moisture and 6% moisture was added to prepare the tempered barley. Tempering had no influence on rate or efficiency of gain for bulls in this study. Degree of grain processing had no effect on gain, however, dry matter intake was decreased and feed efficiency was improved as degree of rolling increased ($P < .05$). Anderson and Bock (2000) used dry-rolled and temper-rolled barley in a growing and finishing beef cattle study (Table 21). As seen in other studies, feed intake was higher for the groups fed the temper-rolled barley. Numerical improvements of 12.4% for average daily gain and 10.4% in feed efficiency were noted.

Hinman and Sorensen (1999) conducted an *in situ* nylon bag degradability study to determine the effect of roasting after tempering on barley ruminal digestibility. They used Westbred 501 barley that was either dry rolled or tempered at 18% moisture then rolled or tempered, roasted and rolled while hot. Roasting barley at the temperature and duration used in their study decreased DM disappearance rate over that of dry-rolled barley (Table 22). Roasting the barley also slowed the CP disappearance rate. The DM disappearance rate was slowed for the roasted barley, but the extent of ruminal degradability was not decreased when compared to dry-rolled or temper-rolled barley. More starch disappeared from the roasted barley in the first few hours of incubation than for dry-rolled or temper-rolled barley.

Four different barley varieties were evaluated for *in situ* DM and starch disappearance rates by Kennington, et al. in 1999. They tempered Idagold, Steptoe, Westbred 501 and Baronesse barley for 24 h then roasted them at three different temperatures for 10 min. The roasted barley was rolled while still hot after being tempered, allowing for starch gelatinization to occur. Starch disappearance rate was similar (Table 23) for all barley varieties, though numerically higher for Baronesse. Roasting increased the starch disappearance rate over the non-roasted barley. Non-roasted barley had lower levels of DM and starch disappearance than the roasted barley (Fig. 1 and 2). They suggest that even though roasting barley increased the overall rate of starch degradation, benefits from roasting may exist.

Flake thickness influences ruminal digestion rate (Zinn, 1990). Previous research (Hinman and Sorensen, 1996; Sorensen and Hinman, 1998) found oven-roasting barley decreased *in situ* DM and starch disappearance rates. So the possibility exists to decrease the ruminal rate of digestion in roasted barley by controlling the flake density of the finished grain. Sorensen and Hinman (2000) roasted tempered Gallatin barley and processed it to obtain three different flake thicknesses (26, 30 or 32 lb/bu). Their results indicate that setting the roller for a thicker flake decreased the DM disappearance rate. Tempering, roasting and rolling barley slowed down the ruminal disappearance rate of DM, CP, and starch to that approximating the rates for dry-rolled grain. Rolling the roasted barley for a thicker flake slowed down DM and starch disappearance rate 40% more than dry-rolled barley and 45% slower than rolling for a thinner flake (Fig. 3 and 4). Reducing the rate of disappearance should address the concern that barley digests too fast, with acidosis and metabolic problems occurring. They also investigated the effect of flake thickness on cattle performance (unpublished data, Table 24). Cattle fed barley that was tempered, roasted and rolled for a flake thickness of 25 lb/bu had the highest gain:feed ratio resulting from a lower feed intake and comparable daily gain to dry-rolled barley.

Research has shown that roasting tempered barley decreases ruminal starch digestion and a thicker flake also decreases ruminal digestion rate. Sorensen and Hinman (2001) treated Gallatin barley by dry rolling, roasting and rolling, or tempering, roasting and rolling and used the treatments in an *in situ* study to determine ruminal disappearance rates. The results of their study indicate that dry roasting then rolling Gallatin barley decreased the rate of ruminal digestion. Crude protein levels remaining at 48 h were similar for all treatments (Fig. 5). Starch levels were also similar (Fig. 6). The presence of free water added during the tempering process gelatinized starch, increasing its digestibility (Rooney and Pflugfelder, 1986) while the dry heat from roasting barley may have formed more protein/starch complexes, thus resisting microbial attack in the rumen.

SUMMARY

Methods for determining quality measurements of barley grain will continue to be evaluated. Improvements in prediction equations and individual quality measurements will occur in the next few years. Bulk density measurements will continue to be the method of determining barley grain quality in commercial applications. This paper has discussed some of the pitfalls of bulk density measurements, however, in practical on-site applications, this is the only measurement that uses simple equipment and is inexpensive. As other measurements, (i.e. starch and fiber content), become easily determined by NIR or other means, producers will add these tools to their assessment of barley quality. Bulk density measurement comparison within varieties seems to be more accurate than between varieties. Variety identification thus is very important in both practical evaluations as well as in research studies.

Barley grain processing and variety evaluations and their influence on animal performance and digestibility of diet components will also be subject to more investigation. The literature cited in this review suggest that barley variety selection will provide livestock feeders with new choices in feed grains. The interaction of variety and processing methods will need to be assessed. Barley grain processing methods that improve the ruminal starch digestion rate and extent, will also improve the digestion of starch in the lower digestive tract and therefore total starch digestion. Processing methods that increase the rate of starch digestion in the rumen have been shown to improve the performance of finishing beef cattle fed high grain diets. The presence of salivary buffers and mastication of feed during time shortly after feed consumption will help decrease the incidence of ruminal acidosis. Digestive upsets, often seen when high barley diets are fed, usually occur four to five hours after feed is consumed. This appears to be related to rates of starch digestion at this delayed time. Processing methods that increase the rate of starch digestion in the early post-eating time periods provide a more balanced rate of starch digestion and, thus, fewer digestive upsets.

It is obvious that beef cattle finishing diets that contain barley as the only source of grain can be fed safely and that high quality barley is comparable to corn as a feed grain.

LITERATURE CITED

Anderson, V. L., and E. Bock. 2000. Evaluation of temper rolled barley and a yeast/enzyme supplement on the performance and carcass traits of growing and finishing feedlot steers. Beef Production Field Day, Carrington Research Extension Center, North Dakota State University Ag. Experiment Station, July 19, Vol 23.

Bowman, J. G. P., T. K. Blake, L. M. M. Surber, D. K. Habernicht, H. Bockelman. 2001. Feed quality variation in the barley core collection of the USDA National Small Grains Collection. Personal communications.

Engstrom, D. F., G. W. Mathison, L. A. Goonewardene. 1992. Effect of β-glucan, starch, and fibre content and steam vs. dry rolling of barley grain on its degradability and utilization by steers. Anim. Feed Sci. Technol., 37:33-46.

Galyean, M. L. and K. J. Malcolm. 1991. Grain processing of Pacific Northwest grains for growing and finishing beef diets. PNW Anim. Nutrition Conf., Beaverton, Oregon.

Grimson, R. E., R. D. Weisenburger, J. A. Basarab, R. P. Stilborn. 1987. Effects of barley volume-weight and processing method on feedlot performance of finishing steers. Can. J. Anim. Sci. 67:43-53.

Hepton, J. R., C. W. Hunt, T. C. Griggs, G. T. Pritchard, P. Feng. 1995. Composition and ruminal fermentability of barley grain, hulls and straw as affected by irrigation level, planting date and variety. Proc. West. Sec. Amer. Soc. Anim. Sci., Vol. 46.

Hinman, D. D. 1978. Barley test weight and beef cattle performance. Proc. PNW Animal Nutrition Conference, p.34.

Hinman, D. D. 1979. A comparison of malting vs. feed barley varieties on beef cattle performance. Proc. West. Sec. Amer. Soc. Anim. Sci. 30:49.

Hinman, D. D. and J. J. Combs. 1983. Tempered versus dry-rolled barley rations for feedlot steers. Proc. West. Sec. Amer. Soc. Anim. Sci. 34:306-307.

Hinman, D. D. and S. J. Sorensen. 1996. *In situ* disappearance of dry matter, protein, fiber and starch as affected by barley variety and processing method. Proc. West. Sec. Amer. Soc. Anim. Sci. 47:277.

Hinman, D. D. and S. J. Sorensen. 1999. Influence of roasting barley on rumen digestibility. Proc. West. Sec. Amer. Soc. Anim. Sci. 50:321-324.

Hinman, D. D., S. J. Sorensen, P. A. Momont. 1995. Influence of barley bulk density and blended barley on the performance of beef cattle and diet digestibility. Proc. West. Sec. Amer. Soc. Anim. Sci. Vol. 46.

Hironaka, R. 1981. Triticale for feedlot cattle. Pages 42-44 *in* G. C. R. Coome and T. G. Atkinson eds. Research highlights – 1980. Agriculture Canada Research Station, Lethbridge, AB.

Jimenez, A. A. 1978. Nutritive value of barley of different bushel weight. In Feedstuffs, December 25, 1978.

Kennington, L. R., D. D. Hinman, C. W. Hunt, J. V. Anderson, J. G. Andrae, G. T. Pritchard, S. J. Sorensen. 1999. Effect of roasting on ruminal *in situ* digestion of four barley varieties (Idagold, Steptoe, 501 and Baronesse). Proc. West. Sec. Amer. Soc. Anim. Sci. 50:262-265.

Khorasani, G. R., J. Helm, J. J. Kennelly. 2000. *In situ* rumen degradation characteristics of sixty cultivars of barley grain. Can. J. Anim. Sci. 80:691-701.

Mathison, G. W. 1996. Effects of processing on the utilization of grain by cattle. An. Feed Sci. Tech. 58:113-125.

Mathison, G. W., D. F. Engstrom, R. Soofi-Siawah, D. Gibb. 1997. Effects of tempering and degree of processing of barley grain on the performance of bulls in the feedlot. Can. J. Anim. Sci. 77:421-429.

Mathison, G. W., R. Hironaka, B. K. Kerrigan, I. Vlach, L. P. Milligan, R. D. Weisenburger. 1991. Rate of starch degradation, apparent digestibility and rate and efficiency of steer gain as influenced by barley grain volume-weight and processing method. Can. J. Anim. Sci. 71:867-878.

Milner, T. J., J. G. P. Bowman, B. F. Sowell. 1995. Effects of barley variety or corn on feedlot performance and feeding behavior. Proc. West. Sec. Amer. Soc. Anim. Sci. 46:539-542.

Milner, T. J., J. G. P. Bowman, L. M. M. Surber, S. D. McGinley, T. K. Daniels, J. T. Daniels. 1996. Feedlot performance and carcass characteristics of beef steers fed corn or barley. Proc. West. Sec. Amer. Soc. Anim. Sci. 47:32-35.

NRC. 1996. Nutrient Requirements of Beef Cattle (7th Ed.). National Academy Press, Washington, DC.

Ovenell, K. H., M. L. Nelson, J. A. Froseth, S. M. Parish, E. L. Martin. 1993. Feedlot performance, carcass characteristics of steers, and digestibility of diets containing different barley cultivars. Proc. West. Sec. Amer. Soc. Anim. Sci., 44:416-419.

Ovenell-Roy, K. H., M. L. Nelson, J. A. Froseth, S. M. Parish, E. L. Martin. 1998. Variation in chemical composition and nutritional quality among barley cultivars for ruminants. 1. Steer finishing performance, diet digestibilities and carcass characteristics. Can. J. Anim. Sci. 78:369-375.

Owens, F. N., D. S. Secrist, W. J. Hill, D. R. Gill. 1997. The effect of grain source and grain processing on performance of feedlot cattle: A review. J. Anim. Sci. 75:868-879.

Rodriquez, S. A., M. F. Montaño, A. Plascencia, R. A. Zinn. 2000. Comparative digestion of steam flaked corn, barley, wheat and oats in finishing diets for feedlot cattle. Proc. West. Sec. Amer. Soc. Anim. Sci. 51:544-548.

Rooney, L. W. and R. L. Pflugfelder. 1986. Factors affecting starch digestibility with special emphasis on sorghum and corn. J. Anim. Sci. 63:1607.

Sanford, B. J., C. W. Hunt, J. G. Andrae, G. T. Pritchard. 2000. Evaluation of barley characteristics that are associated with digestible energy. Proc. West. Sec. Amer. Soc. Anim. Sci. 51:419-422.

Sorensen, S. J and D. D. Hinman. 2000. Influence of flake thickness of roasted barley on *in situ* ruminal rate and extent of digestion of dry matter, protein, fiber and starch in cattle. Proc. West. Sec. Amer. Soc. Anim. Sci. 51:429-432.

Sorensen, S. J. and D. D. Hinman. 1998. *In situ* disappearance of dry matter, fiber, protein and starch as affected by tempering and roasting of Idagold barley. Proc. West. Sec. Amer. Soc. Anim. Sci. 49:264.

Sorensen, S. J. and D. D. Hinman. 2001. Effect of roasting dry or tempered Gallatin barley on *in situ* extent and rate of ruminal disappearance. Proc. West. Sec. Amer. Soc. Anim. Sci. 52:573-576.

Surber, L. M. M., J. G. P. Bowman, T. K. Blake, D. D. Hinman, D. L. Boss, T. C. Blackhurst. 2000. Prediction of barley feed quality for beef cattle from laboratory analyses. Proc. West. Sec. Amer. Soc. Anim. Sci. 51:454-457.

Theurer, C. B., O. Lozano, A. Alio. 1996. Ruminal vs. intestinal starch digestion affects nutrient use and efficiency of gain in feedlot cattle. Proc. Southwest Nutrition and Management Conference, Phoenix, Arizona.

Thomas, O. O., L. Myers, J. Matz. 1962. Feeding value of light and heavy barley fed with and without a protein supplement. Montana State College, Montana Agricultural Experiment Station, Animal Science and Range Management Department, A.S. Leaflet No. 49. September 1962.

Zinn, R. A. 1990. Influence of flake density on the comparative feeding value of steam-flaked corn for feedlot cattle. J. Anim. Sci. 68:767-775.

Zinn, R. A. 1993. Influence of processing on the comparative feeding value of barley for feedlot cattle. J. Anim. Sci. 71:3-10.

Zinn, R. A., M. Montaño, Y. Shen. 1996. Comparative feeding value of hulless vs. covered barley for feedlot cattle. J. Anim. Sci. 74:1187-1193.

Table 1. Weight gains and feed cost of steers fed light or heavy barley with and without a protein supplement

	Lot Number			
	1	2	3	4
Type of barley	Light (45 lb/bu)	Heavy (50 lb/bu)	Light (45 lb/bu)	Heavy (50 lb/bu)
Protein in barley, %	17	13	17	13
Supplement (1 lb/day)	Barley	Barley	20%	20%
No. steers	9	9	9	9
Avg daily gain, lb	2.24	2.28	2.38	2.46
Avg daily ration, lb	16.79	16.79	17.19	17.19
Feed per cwt gain, lb	748	725	724	694
Feed cost per cwt gain, $	16.01	15.99	15.92	15.30
NE_m, Mcal/100 lb	88.39	89.80	89.19	89.71
NE_g, Mcal/100 lb	58.88	60.11	59.58	60.04

From Thomas, et al. 1962

Table 2. Composition of barley

	Barley weight (lb/bu)			
	51	49	45	42
Crude protein	9.19	10.40	10.62	10.95
ADF	8.52	7.63	8.90	9.60
Fat	2.38	1.80	2.54	2.52
Ash	2.80	2.64	3.19	2.76
NFE[a]	77.11	77.53	74.75	74.17

[a] Calculated using acid detergent fiber.

From Hinman, 1978

Table 3. Influence of barley test weight on performance of finishing beef cattle

	Barley weight (lb/bu)			
	51	49	45	42
No. head	16	16	16	16
Avg daily gain, lb	2.84[a]	2.73[ab]	2.75[ab]	2.52[b]
Daily feed consumption, lb DM	20.1	19.8	20.2	19.5
Feed efficiency, lb feed/lb gain	7.08	7.25	7.35	7.74
NE_m, Mcal/100 lb	95.9	95.4	94.5	94.0
NE_g, Mcal/100 lb	65.3	64.8	63.7	62.7

[a,b] Values with different superscripts differ, $P < .05$.

From Hinman, 1978

Table 4. Volume weight, moisture and various chemical components of light, medium and heavy barley prior to processing, and average daily gain, dry matter intake and feed intake to gain ratio for yearling steers

	Light 37 lb/bu	Medium 43 lb/bu	Heavy 51 lb/bu
Volume weight, kg/hL			
Mill	46.9	55.4	66.6
Laboratory	47.8	55.6	66.6
Moisture, % air dry	8.9	9.3	11.0
Crude protein, % DM	16.1	15.3	11.1
ADF, % DM	9.0	5.8	5.5
ADG, kg	1.62	1.72	1.69
DMI, kg	9.34	9.15	8.89
DM intake:Gain	5.80	5.32	5.26

From Grimson, et al. 1987

Table 5. Comparison of light, medium and heavy barley

	Volume weight (lb/bu)		
	33	46	50
Dry matter, %	86.4	85.7	87.3
CP, %	10.8[b]	12.4[a]	12.6[a]
ADF, %	9.0[c]	6.4[c]	6.8[d]
Starch, %	57.3[b]	62.8[a]	62.9[a]
Density, kg DM/L	0.31	0.45	0.49
Effect upon steer performance during 83-d trial			
No. animals	30	30	29
Daily gain, kg	1.63	1.67	1.65
DM intake, kg/d	10.21	9.87	9.84
DM intake:gain	6.29	5.89	6.00

[a,b] Means not followed by the same letter differ ($P < .01$).
[c,d] Means not followed by the same letter differ ($P < .05$).

From Mathison, et al. 1991

Table 6. Barley composition

	Dry matter basis					
Bulk density lb/bu	DM %	CP %	Ash %	NDF %	ADF %	Starch %
52	94.05	8.58	2.93	18.84	7.27	56.53
48 Blend	93.99	8.82	2.92	19.30	7.59	54.13
44	93.80	9.54	3.07	20.66	8.08	52.03
45 Blend	93.94	8.43	3.05	19.54	8.28	54.05
38 Blend	93.91	8.45	3.41	24.54	8.61	51.39
35	93.53	8.51	3.47	23.03	9.47	48.56

From Hinman, et al. 1995

Table 7. Influence of barley bulk density on steer performance

Bulk density lb/bu	Initial wt kg	Final wt kg	ADG kg/d	DMI kg/d	Gain/Feed g/kg
52	345	543	1.63[a]	9.69	168.4[a]
48 Blend	346	546	1.57[ab]	9.66	162.1[ab]
44	339	533	1.57[ab]	9.54	164.2[ab]
45 Blend	340	539	1.56[ab]	9.82	159.3[b]
38 Blend	346	541	1.54[ab]	9.47	162.3[ab]
35	346	534	1.52[b]	9.61	158.2[b]
SE	4.06	6.91	.04	.17	2.94

[a,b] Values with different superscripts differ ($P < .05$)

From Hinman, et al. 1995

Table 8. Effect of variety on chemical composition and ruminal degradability of barley grain[a]

			Variety			
Item[b]	PD	IL	Steptoe	Colter	Lud	Gallatin
Bulk density, lb/bu		Low	50.8[c]	52.2[d]	54.5[e]	55.6[e]
		High	50.7[c]	51.7[c]	53.9[d]	55.2[e]
Hull, %	11 May		19.6[e]	16.6[c]	18.1[d]	17.3[c]
	25 May		19.3[e]	15.9[c]	17.5[d]	16.5[c]
NDF, %			22.6[e]	19.7[d]	20.0[d]	18.2[c]
ADF, %			7.0[e]	5.1[cd]	5.4[d]	4.7[c]
CP, %			9.7[d]	9.2[c]	10.9[e]	10.9[e]
Starch, %			54.3[c]	57.0[d]	56.6[d]	57.5[d]
ISDMD, %			80.0[c]	82.5[d]	82.4[d]	82.1[d]

[a] Varieties were cultivated at two planting dates (PD) and irrigation levels (IL; 50 and 100% of calculated evapotranspiration following seed head emergence). Values for varieties at each PD or IL are provided when an interaction ($P < .10$) was observed.

[b] Values except bulk density are expressed on a DM basis. ISDMD = *in situ* DM disappearance after a 12 h incubation.

[c,d,e] Values within a row with no superscripts in common differ ($P < .05$).

From Hepton, et al. 1995

Table 9. Components of barley grain dry matter prior to processing

	Barley lot number					
	1	2	3	4	5	6
β-Glucans, %	3.5[c]	3.9[b]	4.1[b]	4.1[b]	4.6[a]	4.8[a]
Starch, %	61.2[b]	61.8[b]	62.0[b]	56.5[c]	64.9[a]	65.6[a]
Protein, %	11.5[b]	13.5[a]	12.9[a]	13.2[a]	12.3[ab]	9.1[c]
ADF, %	8.5[b]	7.1[c]	6.7[d]	9.7[a]	5.7[e]	6.3[d]
Volume wt[1], lb/bu	45.7[c]	44.1[d]	51.4[b]	46.2[c]	52.1[b]	54.3[a]

[1] Volume weight and moisture are given on an air dry basis.
[a,b,c,d,e] Means not followed by the same superscript differ significantly (P < .05).

From Engstrom, et al. 1992

Table 10. Performance and carcass characteristics of steers

	Barley lot number					
	1	2	3	4	5	6
No. animals	20	20	20	19	20	20
Daily gain, kg/day	1.49	1.57	1.53	1.55	1.56	1.56
DM intake, kg/day	9.42	9.72	9.09	9.77	9.11	9.19
DM intake:gain	6.35	6.12	5.97	6.34	5.85	5.92

From Engstrom, et al. 1992

Table 11. Feedlot performance and intake of finishing steers and digestibility of diets containing different barley cultivars

	Barley cultivar					
	Boyer	Camelot	Clark	Harrington	Hesk	Steptoe
Starch, %	60.1	56.7	62.8	62.5	58.4	57.4
NDF, %	23.8	20.8	17.3	20.9	25.1	24.5
OMI, kg/d	10.1	10.2	10.2	10.1	10.6	10.0
ADG, kg/d	1.5	1.7	1.6	1.7	1.6	1.6
Feed-to-gain	6.7[b]	6.2[ab]	6.3[ab]	5.9[a]	6.8[c]	6.5[b]
OM digestibility, %	66.3[e]	70.2[f]	70.0[f]	68.7[ef]	63.0[d]	68.6[ef]
Energy digestibility, %	62.5[e]	67.3[f]	65.9[ef]	64.4[ef]	58.6[d]	65.6[ef]
Diet DE, Mcal/kg OM	2.6[e]	2.8[f]	2.7[ef]	2.6[e]	2.4[d]	2.7[ef]
Volume wt, lb/bu	54.0	50.2	49.4	53.7	51.7	49.2

[a,b,c] Means within a row with different superscripts differ ($P < .10$).
[d,e,f] Means within a row with different superscripts differ ($P < .05$).

Adapted from Ovenell, et al. 1993 and Ovenell-Roy, et al. 1998.

Table 12. Characteristics of corn and barley varieties

	Corn	Barley varieties	
		Condor[a]	Leduc[b]
Dry matter, %			
Whole	86.3	87.3	86.8
Dry-rolled	--	86.2	86.2
Steam-flaked[c]	80.3	81.2	81.4
Ash, %	.8	1.4	2.0
ADF, %	3.7	3.4	9.0
Starch, %	72.6	57.6	54.8
Crude protein, %	8.5	12.1	11.2
Density, lb/bu			
Whole	54.3	58.9	48.0
Starch reactivity, %[d]			
Dry-rolled	--	8.7	9.0
Steam-flaked	23.0	33.2	27.8

[a] Hulless barley.
[b] Covered barley.
[c] Measurements taken on grain as it exited the rollers.
[d] Amyloglucosidase reactivity, a measure of starch solubilization. Grains were ground to pass through a 20-mesh screen before enzymatic digestion.

From Zinn, et al. 1996

Table 13. Correlations between animal performance, *in vivo* digestibility and laboratory analyses of barley-based feedlot diets

	ADG	Barley ADF	Barley starch	Particle size	Barley NE_m	Barley NE_g	DM digestibility	DM intake	Starch intake	Gain/ feed
Barley ISDMD										
r^x =	-0.36	NS[y]	-0.25	-0.44	-0.59	-0.60	0.52	0.22	0.27	-0.37
P =	0.007	NS	0.06	0.003	<0.001	<0.001	0.002	0.11	0.10	0.007
Barley ADF										
r =	NS	---	-0.48	NS	-0.21	-0.22	NS	0.20	-0.45	NS
P =	NS	---	<0.001	NS	0.19	0.16	NS	0.17	0.008	NS
Barley starch										
r =	NS	---	---	NS	0.34	0.37	NS	-0.29	NS	0.33
P =	NS	---	---	NS	0.02	0.01	NS	0.04	NS	0.02
Particle size										
r =	NS	---	---	---	NS	NS	-0.68	-0.31	NS	0.35
P =	NS	---	---	---	NS	NS	<0.001	0.04	NS	0.02
Barley NE_m										
r =	0.32	---	---	---	---	0.99	-0.29	-0.71	-0.57	0.76
P =	0.03	---	---	---	---	<0.001	0.11	<0.001	<0.001	<0.001
Barley NE_g										
r =	0.32	---	---	---	---	---	-0.28	-0.71	-0.54	0.76
P =	0.03	---	---	---	---	---	0.11	<0.001	<0.001	<0.001
DM digestibility										
r =	-0.33	---	---	---	---	---	---	NS	NS	-0.31
P =	0.07	---	---	---	---	---	---	NS	NS	0.08
DMI										
r =	0.48	---	---	---	---	---	---	---	0.77	-0.70
P =	<0.001	---	---	---	---	---	---	---	<0.001	<0.001
Starch intake										
r =	0.53	---	---	---	---	---	---	---	---	-0.38
P =	<0.001	---	---	---	---	---	---	---	---	0.01
Gain/feed										
r =	0.27	---	---	---	---	---	---	---	---	---
P =	0.05	---	---	---	---	---	---	---	---	---

[x]r = Pearson correlation coefficient.
[y]NS = Non-significant (*P* > .20).

From Surber, et al. 2000

Table 14. Effect of source of barley on diet and calculated barley digestibility

	Barley source							
	A	B	C	D	E	F	G	H
CP, % DM basis	10.2	11.5	9.6	10.4	11.8	14.0	10.7	11.0
Starch, % DM basis	62.9	60.5	60.0	54.0	57.0	58.0	54.7	57.4
NDF, % DM basis	18.5	17.8	19.8	25.6	19.0	20.8	24.3	22.0
ADF, % DM basis	4.6	4.8	5.4	9.6	5.2	5.6	8.8	6.8
Bulk density, lb/bu	51.4	51.7	47.6	46.6	54.5	49.4	44.2	45.3
Barley digestibility								
DM, %	89.9[de]	90.1[e]	92.3[e]	77.1[a]	84.4[bc]	88.7[cde]	83.3[b]	85.7[bcd]
GE, %	88.2[de]	88.2[e]	90.7[e]	75.6[a]	82.4[bc]	87.5[cde]	81.6[b]	83.6[bcd]

[a,b,c,d] Values with different superscripts differ (*P* < .05).

From Sanford, et al. 2000

Table 15. Influence of grain processing on growth performance of feedlot steers and net energy value of the diet

	Steam-flaked corn	Dry-rolled barley	Steam-rolled barley Coarse flake	Steam-rolled barley Thin flake	SD
Weight gain, kg/d[a]	1.21	1.31	1.29	1.28	.06
DM intake, kg/d[bc]	6.44	7.53	7.25	7.00	.27
Gain/DM intake[de]	0.188	0.173	0.177	0.184	.006
DM intake/gain[de]	5.33	5.77	5.63	5.45	.16
Diet net energy, Mcal/kg					
Maintenance[bc]	2.28	2.10	2.15	2.21	.05
Gain[bc]	1.58	1.43	1.47	1.53	.04
Obs/expected diet net energy					
Maintenance[cdg]	1.00	1.01	1.03	1.06	.02
Gain[cdg]	1.00	1.00	1.03	1.07	.03
NE of barley, Mcal/kg[f]					
Maintenance	--	2.14	2.20	2.29	--
Gain	--	1.47	1.52	1.60	--

[a] Steam-flaked corn vs dry-rolled, steam-rolled coarse, and steam-rolled thin barley, $P < .10$.
[b] Steam-flaked corn vs dry-rolled, steam-rolled coarse, and steam-rolled thin barley, $P < .01$.
[c] Dry-rolled vs steam-rolled coarse and steam-rolled thin barley, $P < .05$.
[d] Steam-flaked corn vs dry-rolled, steam-rolled coarse, and steam-rolled thin barley, $P < .05$.
[e] Dry-rolled vs steam-rolled coarse and steam-rolled thin barley, $P < .10$.
[f] Based on the assumption that steam-flaked corn has a NE_m and NE_g of 2.38 and 1.67 Mcal/kg, respectively (NRC, 1984).
[g] Steam-rolled coarse vs steam-rolled thin barley, $P < .10$.

From Zinn, 1993

Table 16. Performance by steers consuming finishing diets containing corn, Harrington barley, Morex barley, or Steptoe barley as basal grains

	Corn	Harrington	Morex	Steptoe	SE	Corn vs barley[a]
No. steers	7	8	8	8		
ADG, kg	1.61	1.42	1.41	1.66	.095	.33
DM intake, kg/d	12.2	9.9	10.3	11.4	.09	.009
Feed/gain	7.9	7.0	7.3	6.9	.47	.16

[a] Comparison of corn vs barley.

From Milner, et al. 1995

Table 17. Performance by steers consuming finishing diets containing corn, Gunhilde barley (GUN), Harrington barley (HAR), or 50/50 Gunhilde and Harrington barley (MIX) as basal grains

						Pr > F		
	Corn	GUN	HAR	MIX	SE	Corn vs barley[a]	MIX vs GUN/HAR[b]	GUN vs HAR[c]
DM intake, kg	14.26	11.74	11.93	12.30	.233	.0001	.13	.54
Starch intake, kg	6.52	5.37	5.45	5.63	.106	.0001	.13	.54
ADG, kg	1.6	1.5	1.5	1.5	.041	.04	.31	.49
Feed:gain	9.1	8.3	8.2	8.3	.239	.01	.94	.81

[a] Comparison of corn vs barley.
[b] Comparison of MIX vs Gunhilde and Harrington barley.
[c] Comparison of Gunhilde vs Harrington barley.

From Milner, et al. 1996

Table 18. Feedlot performance of steers fed tempered versus dry-rolled barley based rations

	Tempered	Dry-rolled
Average daily gain, kg	1.15[a]	1.06[b]
Average daily dry feed, kg	8.45[a]	8.08[b]
Average feed conversion	7.35	7.62

[a,b] Means in the same row bearing different superscripts differ significantly (P < .05).

From Hinman and Combs, 1983

Table 19. Average feed intake, rates of gain, and feed-to-gain ratios for Hereford and Angus steers

Diets and treatment	Feed intake (kg/day)	Avg gain (kg/day)	Feed-to-gain ratio
Barley			
Tempered-rolled	7.69[a]	1.32[a]	5.82[a]
Dry-rolled	7.31[a]	1.09[b]	6.71[a]

[a,b] Within a column, values followed by the same letter do not differ (P < .05).

From Hironaka, 1981

Table 20. Dry matter intake, daily gain, conversion of feed dry matter to live-weight gain of bulls

	Moisture treatment		Degree of processing		
	Control	Tempered	Slight	Medium	Crushed
Daily gain, kg	1.58	1.58	1.55	1.57	1.61
DM intake, kg/d	7.81	7.77	8.04[a]	7.79[b]	7.54[b]
DM intake:gain	4.96	4.93	5.20[a]	4.96[b]	4.68[a]

[a,b] Means within the same row and comparison not followed by the same letter differ significantly (P < .05).

From Mathison, et al. 1997

Table 21. Performance of steers fed temper vs. dry-rolled barley

	Dry-rolled	Temper-rolled
Dry matter intake, lb/d		
Growing	21.77	21.18
Finishing	23.03	23.51
Overall	22.52	22.57
Average daily gain, lb/d		
Growing	4.22	4.13
Finishing	2.65	2.98
Overall	3.28	3.44
Gain per unit feed		
Growing	.196	.196
Finishing	.115	.127
Overall	.147	.154

From Anderson and Bock, 2000

Table 22. Influence of roasting barley on *in situ* dry matter, starch and CP disappearance rate, %/h

Incubation period	DR[1]	TR	RST	SE
		Dry Matter		
0-4 h	12.54[a]	16.68[ab]	25.91[b]	3.80
6-48 h	12.11[a]	6.02[b]	5.90[b]	.90
0-48 h	11.81[a]	9.42[b]	8.93[b]	.69
		Starch		
0-4 h	2.56[a]	1.94[a]	22.64[b]	2.59
6-48 h	3.12[a]	2.17[b]	3.43[a]	.29
0-48 h	4.41[ab]	3.51[a]	5.41[b]	.53
		Crude Protein		
0-4 h	6.64[a]	9.50[ab]	2.99[b]	1.89
6-48 h	5.46[a]	2.89[b]	3.62[b]	.36
0-48 h	5.67[a]	3.34[b]	3.44[b]	.28

[1] Treatments: DR = dry-rolled, TR= temper-rolled, RST = temper-roasted-rolled barley.

[a,b] Within a row, means lacking a common superscript differ ($P < .10$).

From Hinman and Sorensen, 1999

Table 23. Dry matter and starch disappearance rates (%/h)

Due to variety	Idagold	Baronesse	501	Steptoe
Dry matter	12.4[a]	10.3[a]	9.9[a]	10.9[a]
Starch	12.7[a]	14.3[a]	12.2[a]	15.1[a]
Due to roasting level	CTRL	LOW	MED	HIGH
Dry matter	10.4[a]	11.2[a]	11.2[a]	11.7[a]
Starch	7.7[b]	15.9[c]	15.2[c]	15.5[c]

[a,b,c]Means within a row lacking a common superscript differ (*P*< .05)

From Kennington, et al. 1999

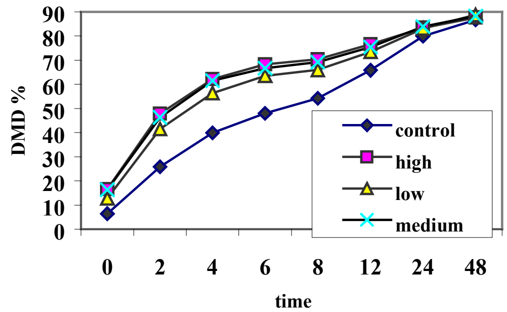
Table 24. Effect of roasted barley flake thickness on cattle performance

	Treatments[1]					
	DRB	DRC	RB26	RB30	RB32	SE
Initial wt, kg	308.5	309.3	309.7	309.0	311.7	2.00
Final wt, kg	519.3	519.4	511.3	508.2	517.3	5.48
ADG, kg/d	1.50[a]	1.44[ab]	1.38[ab]	1.38[b]	1.42[ab]	.03
DMI, kg/d	8.47[a]	8.09[b]	7.18[c]	7.42[c]	7.84[b]	.13
GF, g/kg	172.5[cd]	177.3[bcd]	192.9[ab]	185.6[abc]	181.1[bcd]	4.08

[1] DRB – dry rolled barley
DRC – dry rolled corn
RB26 – roasted rolled barley 26 lb/bu
RB30 – roasted rolled barley 30 lb/bu
RB32 – roasted rolled barley 32 lb/bu
[a,b,c,d] Within a row, means lacking a common superscript differ, P < .05.

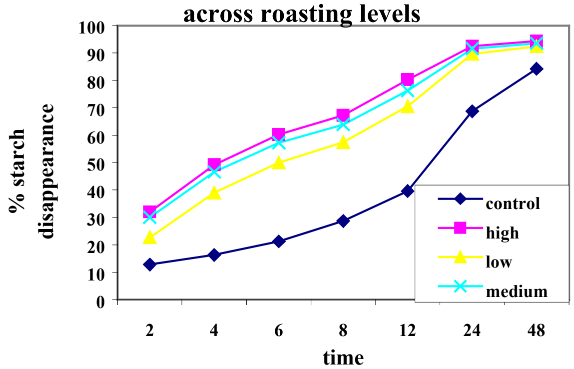
From Hinman and Sorensen, unpublished data

Figure 1. Dry matter disappearance by hour across roasting levels



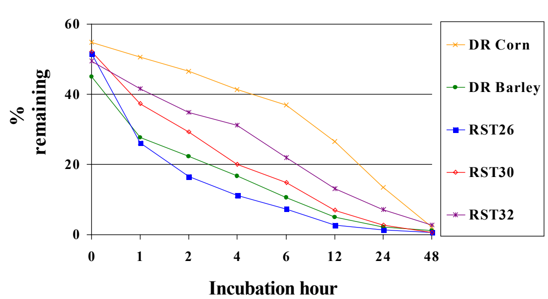
From Kennington, et al. 1999

Figure 2. Starch disappearance by hour across roasting levels



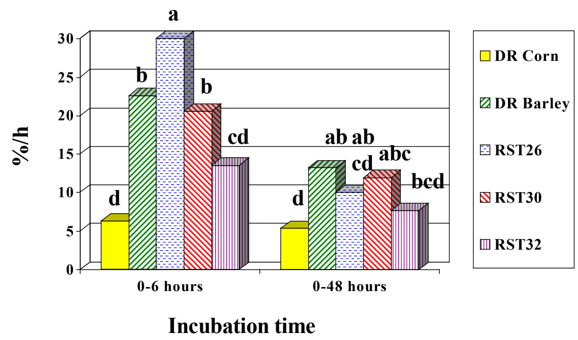
From Kennington, et al. 1999

Figure 3. ***In situ*** **starch remaining, by hour**



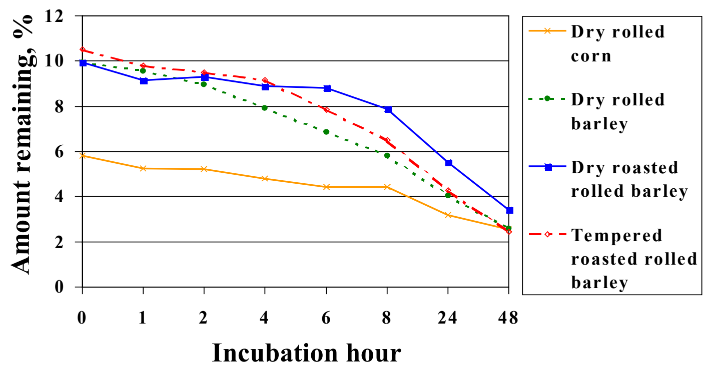
From Sorensen and Hinman, 2000

Figure 4. *In situ* starch disappearance rates as influenced by flake thickness



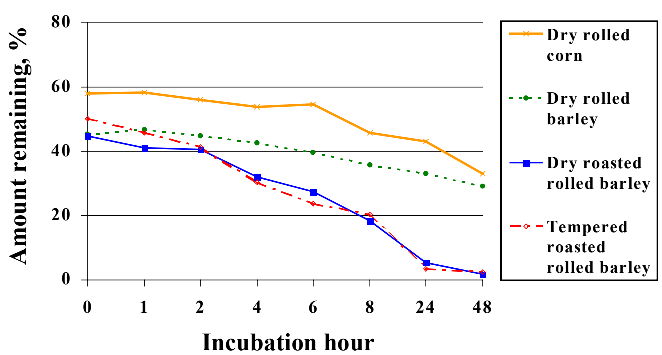
From Sorensen and Hinman. 2000

Figure 5. *In situ* CP remaining, by hour



From Sorensen and Hinman, 2001

Figure 6. *In situ* starch remaining, by hour



From Sorensen and Hinman, 2001